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CHEMISTRY AND PHYSICS.

A MANUAL FOR STUDENTS AND PRACTITIONERS.

BY

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PREFACE.

In the education of medical students a knowledge of chemistry and physics is important, though from a practical point of view it need not be exhaustive. Embracing, as they do, two distinct sciences and professions, "Chemistry and Physics" could not be presented in a volume of this size were it intended for the use of students of these sciences. But for medical students, for whom especially the book is prepared, it is believed by the authors, themselves medical men, that the manual contains everything necessary. The book is also intended for practitioners who may desire to look up forgotten points, but who may not have time or opportunity to consult larger works.

Although written for medical students and graduates, the general plan of the book is, one may say, purely "chemical and physical," as may be instanced by the introduction of "Wireless Telegraphy" in the section on physics. To have the plan otherwise—*i. e.* to give undue prominence to the medical aspect of certain chemicals which are also drugs, and to certain uses of electricity which are employed in the treatment of disease—would be in the authors' opinion, an encroachment upon Materia Medica and Electro-therapeutics, both of which subjects are treated of in other books of this series.

At the same time those compounds, especially in the section on *Organic Chemistry*, which are of medical interest not only medicinally, but in *physiological chemistry* (a very important and comparatively modern branch of instruction for medical students) have received more detailed descriptions than have been given to compounds of value only to the chemist.

Illustrations have not been forgotten. Most if not all of the chief topics in Physics are made clearer, it is hoped, by appropriate cuts.

The sections on Organic Chemistry and Physics have been written, the former by Dr. Martin the latter by Dr. Rockwell. The section on Inorganic Chemistry is based on the book of Mr. Joseph Struthers.

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CHEMISTRY AND PHYSICS.

CHEMISTRY.

INTRODUCTION.

CHEMICAL DEFINITION AND GENERAL CONSIDERATIONS.

Definition of chemistry: Chemistry is the science which investigates the composition of all substances, together with the combinations and decompositions resulting from their action upon one another under the influence of chemical force.

Material bodies are made up of an unending variety of substances, and *chemical science* deals with the relations of these substances. In a world consisting of only one substance, the relations of mass and energy which are studied in *physics* might be observed, but there could be no chemistry. The distinctions of substances are therefore the basis of the science. In most cases the distinctions are obviously striking. No person would confound water, air, iron, and glass; but in many cases it requires close observation and careful study to distinguish differences.

The distinction between physical and chemical change: An example of this distinction is afforded by mixing yellow sulphur and black iron-filings. As a result, a mixture of a greenish-yellow color is obtained. By examining this mixture with a microscope each particle of iron and sulphur can be identified by sight, and a separation can be made by using a magnet, the particles of iron being gathered up by it, leaving the sulphur, which is not attracted, thus giving us what we started with, iron and sulphur. The change here was one of color, resulting from mixing a yellow substance with a black one; but the iron and sulphur in the mixture are the same as before the mixing. Such a change as this is merely a change in state, a physical change, and such a mixture would be called a *mechanical mixture.*

If these iron and sulphur powders be mixed together, placed in a test-tube, and heat applied, we see a different kind of a change. The sulphur will become soft, pasty, and finally liquid; then the bottom of the mass will begin to glow, getting red-hot. The glow then extends throughout the mixture, even *after* the flame has been removed, and the entire mixture becomes red-hot from heat generated in itself. This is evidently a new kind of phenomenon. On breaking the tube and removing the contents we obtain a homogeneous mass in which we cannot recognize the original particles of yellow sulphur or gray-black iron, nor will the magnet attract the latter. The change here has evidently been one affecting the nature of the substances, and is called a *chemical change.*

Divisions of matter: All matter is divided into two kinds, simple and compound. The simple form of matter is that which cannot be subdivided, and is called elementary matter, or an *element.* Compound matter is made up of elementary substances, and can be divided into the elements which compose it.

Definition of an atom: An atom is the smallest particle of matter that can exist in a state of combination. Each atom of an element is identical with every other atom of the same element and differs from the atoms of all other elements.

It is assumed that all matter is made up of indivisible atoms, and that in the chemical union of these atoms, one with another, only whole atoms or multiples can unite, fractions of atoms being unknown.

When hydrogen and oxygen unite chemically, they do so in proportions representing either the relative weights of their atoms or simple multiples thereof. Similar rules govern the combinations of all the elements. It is assumed, therefore, that the combining weights represent the relative weights of the different atoms compared with hydrogen as unity—that is, an atom of oxygen weighs sixteen times as much as an atom of hydrogen, an atom of sulphur thirty-two times as much, and one of nitrogen fourteen times as much, etc. These values are called the *atomic weights* of the elements, a full table of which is given later on. As to the real weights of the atoms we have no definite knowledge, but we are positive concerning the comparative weights.

Molecular weight of compounds: The molecular weight of a compound is the sum of the atomic weights of the atoms which compose the molecule.

Definition of a molecule: Of the given substance a molecule is the smallest particle that can exist and maintain its identity.

Three classes of molecules: (1) Those molecules whose atoms are of the same kind; as all hydrogen, H_2; all oxygen, O_2, etc.

(2) Those molecules whose atoms are of different kinds; as hydrogen and oxygen, H_2O (water); carbon and oxygen, CO_2 (carbon dioxide), etc.

(3) Those molecules whose constituent atoms are alike in kind and proportion, but whose arrangement of the atoms differs. Starch, dextrine, and cellulose are compounds differing from one another in properties, although the composition is of the same elements taken in the same quantities.

n times $C_6H_{10}O_5$ represents each of these three compounds.

Analysis is the method of separating a body into its component parts and of identifying them.

Synthesis is the method of combining component parts artificially so as to produce the substance under consideration.

Definition of an element: An almost limitless number of different substances occur in nature, and are made artificially, in which the same component parts are continually repeated in various modes of union. Upon analysis, bodies are finally obtained so simple that they cannot be analyzed further. These simple substances number about seventy, and are called *elements*. All other substances, being necessarily made up of combinations of elements, are called *compounds*.

The **elements are divided** into the metal and the non-metals.

The *metals* are characterized by certain properties—viz., lustre, weight, good conductivity of heat and electricity, ductility, malleability, tenacity, and opacity.

The term *non-metallic* embraces the rest of the elements. The line of division is not sharply defined. Some elements, like arsenic, may be fairly put in either class.

TABLE OF ATOMIC MASSES.

REVISED BY F. W. CLARKE,

Chief Chemist of the United States Geological Survey.

OCTOBER, 1891.

ELEMENTS.	SYMBOL.	ATOMIC WEIGHT.	ELEMENTS.	SYMBOL.	ATOMIC WEIGHT.
Aluminium . .	Al	27.	Neodymium . .	Nd	140.5
Antimony . .	Sb	120.	Nickel . . .	Ni	58.7
Arsenic . . .	As	75.	Nitrogen . . .	N	14.03
Barium . . .	Ba	137.	Osmium . . .	Os	190.8
Bismuth . . .	Bi	208.9	Oxygen . . .	O	16.
Boron	B	11.	Palladium . .	Pd	106.6
Bromine . . .	Br	79.95	Phosphorus . .	P	31.
Cadmium . .	Cd	112.	Platinum . .	Pt	195.
Caesium . . .	Cs	132.9	Potassium . .	K	39.11
Calcium . . .	Ca	40.	Praseodymium .	Pr	143.5
Carbon . . .	C	12.	Rhodium . .	Rh	103.
Cerium . . .	Ce	140.2	Rubidium . .	Rb	85.5
Chlorine . . .	Cl	35.45	Ruthenium . .	Ru	101.6
Chromium . .	Cr	52.1	Samarium . .	Sm	150.
Cobalt	Co	59.	Scandium . .	Sc	44.
Columbium . .	Cb	94.	Selenium . . .	Se	79.
Copper . . .	Cu	63.6	Silicon . . .	Si	28.4
Erbium . . .	Er	166.3	Silver	Ag	107.92
Fluorine . . .	F	19.	Sodium . . .	Na	23.05
Gadolinium . .	Gd	156.1	Strontium . .	Sr	87.6
Gallium . . .	Ga	69.	Sulphur . . .	S	32.06
Germanium . .	Ge	72.3	Tantalum . .	Ta	182.6
Glucinum . . .	Gl	9.	Tellurium . .	Te	125.
Gold	Au	197.3	Terbium . . .	Tb	160.
Hydrogen . .	H	1.007	Thallium . . .	Tl	204.18
Indium . . .	In	113.7	Thorium . . .	Th	232.6
Iodine	I	126.85	Thulium . . .	Tu	170.7
Iridium . . .	Ir	193.1	Tin	Sn	119.
Iron	Fe	56.	Titanium . .	Ti	48.
Lanthanum . .	La	138.2	Tungsten . . .	W	184.
Lead	Pb	206.95	Uranium . . .	U	239.6
Lithium . . .	Li	7.02	Vanadium . .	V	51.4
Magnesium . .	Mg	24.3	Ytterbium . .	Yb	173.
Manganese . .	Mn	55.	Yttrium . . .	Yt	89.1
Mercury . . .	Hg	200.	Zinc	Zn	65.3
Molybdenum .	Mo	96.	Zirconium . .	Zr	90.6

ARRANGEMENT OF ELEMENTS IN THE ORDER OF THEIR ATOMIC WEIGHTS.

Series.	Group I. Valency 1. Oxide R_2O.	Group II. Valency 2. Oxide RO.	Group III. Valency 3. Oxide R_2O_3.	Group IV. Valency 4. Oxide RO_2. Hydride RH_4.	Group V. Valency 3–5. Oxide R_2O_5. Hydride RH_3.	Group VI. Valency 2–6. Oxide RO_3. Hydride RH_2.	Group VII. Valency 1–7. Oxide R_2O_7. Hydride RH.	Group VIII. Valency 2–8.
1	H = 1							
2	Li = 7	Be or Gl = 9 —	B = 11 —	C = 12	N = 14 —	O = 16 —	F = 19	
3	Na = 23	Mg = 24	Al = 27.3 —	Si = 28	P = 31 —	S = 32 —	Cl = 35.4	
4	K = 39	— Ca = 40	— Sc = 44	Ti = 48	— V = 51	— Cr = 52.4	— Mn = 55	Fe = 56 Ni = 59 Co = 59
5	— Cu = 63	Zn = 65 —	Ga = 69.8 —	—	As = 75 —	Se = 79 —	Br = 80 —	
6	Rb = 85 —	— Sr = 87	— Y = 89	Zr = 90	— Cb or Nb = 94	— Mo = 95.6	— —	Ru = 103.5 Pd = 106 Rh = 104
7	— Ag = 108	Cd = 111.6 —	In = 113.4 —	Sn = 119	Sb = 122 —	Te = 128 —	I = 126	
8	Cs = 133 —	— Ba = 137	— La = 139	Ce = 141.2	Di = 147 Ta = 182	— W = 184	— —	Os = 199 Ir = 197 Pt = 197
9	— Au = 196	Hg = 200 —	Tl = 204 —	Pb = 206	Bi = 210 —	— —		
10	— —	— —	— —	Th = 231.5		U = 240		

Divisions of chemistry: For convenience of study it is customary to consider the chemistry of the *carbon compounds* separately under the heading *Organic Chemistry*.

The chemistry of all other bodies is designated as *Inorganic Chemistry*.

The **variation of the elements in their chemical relations** is remarkably regular, and seems to be governed by some definite law. If the *physical properties* of the elements be studied, similar regularities are found; and it is now generally believed, although not as yet fully proved, that all the properties of an element depend in some way upon its atomic weight. For example, the specific heat of an element is inversely proportional to its atomic weight.

Arranging the elements in horizontal lines (see preceding table) according to the order of their atomic weights, we find that, with the exception of certain metals belonging to the iron and platinum groups, they all arrange themselves in such a manner that the first vertical column is occupied by the monad elements, the second by the dyads, the third by the triads, etc. Hydrogen itself stands alone, there being no known element intermediate between it and the monad metal lithium. This relation of the elementary bodies, which is called the "*periodic law*," was first pointed out by Newlands in 1864, and afterward developed by Odling and Mendelejeff.

CHEMICAL NOMENCLATURE.

The **symbols** of the elements are derived directly from their names—*e. g.*, sulphur, symbol S; or their Latin or Greek equivalents—*e. g.*, iron, Latin equivalent Ferrum, symbol Fe.

The **number of atoms** of an element in a molecule is indicated by a subscribed numeral:

MnO_2, DI oxide of manganese or manganese DI oxide;
SO_3, TRI oxide of sulphur or sulphur TRI oxide;
Fe_2O_3, SESQUI oxide of iron or iron SESQUI oxide;
PCl_5, PENTA chloride of phosphorus or phosphorus PENTA chloride, etc.

No absolute rules can be given for the **naming of chemical compounds.** The following table has general application :

Termination of acid name.	Termination of salt derived from acid.
(1) ——ic acids produce . . .	——ate salts.
(2) ——ous " " . . .	——ite "
(3) Hypo——ous acids produce .	Hypo——ite salts.
(4) Per——ic " " .	Per——ate "

Example.—(1) Sulphuric acid, H_2SO_4, when combined with sodium, Na, produces sodium sulphATE, Na_2SO_4. Carbonic acid, H_2CO_3, with potassium, K, produces potassium carbonATE, K_2CO_3.

(2) SulphurOUS acid, H_2SO_3, combines with sodium, Na, producing sodium sulphITE; and chlorOUS acid, $HClO_2$, combining with potassium, K, produces potassium chlorITE, $KClO_2$.

(3) The terms HYPO—— and PER—— mean, respectively, "*less than*" and "*more than,*" referring to the oxygen contents of the compound. Thus we have the salts:

$NaClO_3$,	sodium chlorATE;
$NaClO_2$,	" chlorITE (less O than ——" ATE);
$NaClO$,	" HYPO chlorITE (less O than ——" ITE");
$NaClO_4$,	" PER chlorATE (more O than ——" ATE").

(4) When there is only one salt of an element, the termination ——IC is used; as NaCl, sodIC chloride; $CaSO_4$, calcIC sulphate. These salts may also be written sodium chloride, calcium sulphate; or, naming the acid first, chloride of sodium, or sulphate of calcium.

The terminations ——IC and ——OUS, when applied to oxyacids (that is, acids containing oxygen), show that the combination with oxygen is twofold; ——" OUS" indicating less oxygen than ——" IC;" as:

SulpurOUS acid	H_2SO_3;
SulphurIC "	H_2SO_4;
PhosphorOUS acid . . .	H_3PO_3;
PhosphorIC " . . .	H_3PO_4;

In similar manner, the terminations ——IC and ——OUS, when applied to oxy-salts, show a twofold combination; as:

FerrOUS sulphate	$FeSo_4$;
FerrIC "	$Fe_2(SO_4)_3$;
MercurOUS chloride . . .	Hg_2Cl_2;
MercurIC " . . .	$HgCl_2$.

In this case ——OUS means relatively more of the *metal* than in the ——IC combination.

The termination ——OUS is sometimes replaced by SUB; as cuprous oxide, Cu_2O, also suboxide of copper.

(5) The termination ——IDE indicates the *absence of oxygen;* as, hydrogen sulphIDE, H_2S; sodium chlorIDE, NaCl; *except* as applied to oxygen itself; as OXIDE; potassium oxide, K_2O; hydrogen OXIDE, H_2O.

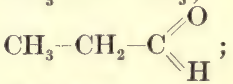
(6) The termination ——IUM or ——UM indicates the element alone; as, sodIUM, Na; strontIUM, Sr; aurUM, Au. The termination ——A indicates the oxide of the element; as, sodA, Na_2O; strontiA, SrO; silicA, SiO_2.

Isomerism: Two compounds are said to be isomeric when they have the same percentage-composition, but show different properties.

They are divided into two classes: (*a*) those that have the same molecular weight are called *metameric;* (*b*) those that have a different molecular weight are called *polymeric.*

(*a*) *Metameric bodies,* or those which have the same percentage-composition and molecular weight, but show different decompositions under similar conditions:

Thus, three bodies correspond to the formula C_3H_6O:

Acetone	$CH_3-CO-CH_3$;
Propionic aldehyde . . .	 $CH_3-CH_2-C{\overset{O}{\underset{H}{\lessgtr}}}$;
Allyl alcohol	C_3H_5OH.

(*b*) *Polymeric bodies*, or those which have the same percentage-composition, but different molecular weights; Thus:

Ethylene	C_2H_4;
Butylene	C_4H_8.

CHEMICAL FORMULÆ.

General considerations regarding chemical formulæ: Each element is represented by a symbol: H = hydrogen, O = oxygen, etc.; and in writing chemical formulæ we render the symbols more precise, letting H, for example, represent not only hydrogen in general, but exactly *one unit weight* of hydrogen, or *one unit volume*, or, more definitely still, *one atom.* Thus O, N, C, etc., represents one atom of each element, respectively; and 16, 14, 12, etc., means *comparative parts by weight.* We represent several atoms of an element by numerals written after the symbols and below the line; as H, H_2, H_3, H_4, etc., for one, two, three, and four atoms of hydrogen.

Water contains 2 unit weights or two volumes of hydrogen combined with 16 unit weights or one volume of oxygen. Its formula, therefore, is H_2O. The symbols are placed side by side to indicate chemical union. Similarly, hydrogen, dioxide is H_2O_2, etc. Perhaps the best examples to cite are the nitrogen compounds, as follows:

Ammonia	NH_3;
Nitrogen mon oxide	N_2O;
Nitrogen di oxide	N_2O_2, NO;
Nitrogen tri oxide	N_2O_3;
Nitrogen tetr oxide	N_2O_4, NO_2;
Nitrogen pent oxide	N_2O_5;
Nitrous acid	HNO_2;
Nitric acid	HNO_3.

These formulæ almost explain themselves. Take, for example, the last one, as it is the most complicated. It shows, first, that nitric acid contains one atom of hydrogen, one atom of nitrogen, and three atoms of oxygen combined together.

Next, that the gases are united by *volume* in the same ratio, 1 : 1 : 3. *By weight* it indicates 1 part of the first element, 14 parts of the second, and (3 times 16) 48 parts of the third. Finally, just as H represents *one atom* of hydrogen, so does HNO_3 represent *one molecule* of nitric acid; and the sum of the atomic weights, $1 + 14 + 48 = 63$, is called the molecular weight of the compound. If we wish to indicate two or more molecules of nitric acid, we write $2HNO_3$ or $xHNO_3$.

All such formulæ as these may be treated in a somewhat mathematical way, so that chemical reactions may be written out in the form of equations. On one side are written the formulæ of the substances with which the reactions begin, and on the other the formulæ of the substances produced by the change. Since matter is indestructible, the sum of the weights of the atoms on one side of the equation must equal the sum of the weights of the atoms on the other side.

Examples of formulæ and equations: In making oxygen gas by heating chlorate of potassium:

$$\begin{array}{lcl}
KClO_3 & = & KCl + O_3 \\
K = 39 & & 39 \\
Cl = 35.5 & & 35.5 + 48 \\
O_3 = 48 & & \\
\overline{\quad 122.5} & & \qquad = 122.5.
\end{array}$$

Again, ammonium nitrate, NH_4NO_3, when heated, separates into nitrogen monoxide and water:

$$\begin{array}{lclcl}
NH_4NO_3 & = & N_2O & + & 2H_2O \\
N = 14 & & N_2 = 28 & & H_2 = 2 \\
H_4 = 4 & & O = 16 & & O = 16 \\
N = 14 & & \quad — & & \quad — \\
O_3 = 48 & & \quad 44 & & H_2O = 18 \\
\quad — & & & & 2H_2O = 36 \\
\quad 80 & & & & 44 + 36 = 80.
\end{array}$$

When sulphuric acid H_2SO_4, is poured on calcium carbonate (limestone), carbon dioxide gas is given off:

$$\begin{array}{ccccccccc}
H_2SO_4 & + & CaCO_3 & = & CaSO_4 & + & H_2O & + & CO_2 \\
\left\{\begin{array}{l} H_2 = 2 \\ S = 32 \\ O_4 = 64 \end{array}\right\} & + & \left\{\begin{array}{l} Ca = 40 \\ C = 12 \\ O_3 = 48 \end{array}\right\} & = & \left\{\begin{array}{l} Ca = 40 \\ S = 32 \\ O_4 = 64 \end{array}\right\} & + & \left\{\begin{array}{l} H_2 = 2 \\ O = 16 \end{array}\right\} & = & \left\{\begin{array}{l} C = 12 \\ O_2 = 32 \end{array}\right\} \\
\overline{98} & & \overline{100} & & \overline{136} & & \overline{18} & & \overline{44}
\end{array}$$

$$98+100=198 \qquad 136+18+44=198.$$

Valency, also called "*quantivalence*" or "*atomicity*,"[1] is the definite capacity which every elementary atom has for uniting with other atoms.

If we combine the non-metallic elements, referring to hydrogen as *one*, we have the following:

I.	II.	III.	IV.
HF	H_2O	H_3N	H_4C
HCl	H_2S	H_3P	H_4Si.
HI	H_2Se	H_3As	
HBr	H_2Te	H_3B	

The elements, thus divided into four groups, are called, respectively, "monads" (or those having one bond of affinity—that is, uniting with one atom of hydrogen to produce a saturated compound);

"Dyads," having two bonds uniting with 2 atoms of H;
"Triads," " three " " " 3 " "
"Tetrads," " four " " " 4 " "

Later on we shall meet with "pentads" and "hexads," representing five and six bonds of affinity respectively.

An element sometimes belongs to more than one group—viz., N may be triad or pentad, but it never has an even valency; and S may be dyad or tetrad, but it never has an odd valency.

The *proportion* in which atoms combine together depends on *valency*. Thus, one monad can unite with one monad; one dyad with one dyad or two monads; one triad with one triad, or one monad and one dyad, or with three monads, etc.

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[1] The term "atomicity" is also applied to designate the number of atoms in a molecule.

The valency is sometimes shown by Roman numerals, or more often by simple dashes:

$Na^{i}Cl^{i}$	$K^{i}Br^{i}$	$Na^{i}I^{i}$	$Ag^{i}Cl^{i}$
$H_2{}^{i}O^{ii}$	$Ag_2{}^{i}O^{ii}$	$Na_2{}^{i}S^{ii}$	$K_2{}^{i}S^{ii}$
$P^{iii}Cl_3{}^{i}$	$As^{iii}Cl_3{}^{i}$	$Sb^{iii}Br_3{}^{i}$	$Bi^{iii}I_3{}^{i}$
$C^{iv}Cl_4{}^{i}$	$C^{iv}Br_4{}^{i}$	$Si^{iv}F_4{}^{i}$	$Si^{iv}I_4{}^{i}$

and

$Ca^{ii}O^{ii}$	$Ba^{ii}S^{ii}$	$Zn^{ii}O^{ii}$	$Hg^{ii}S^{ii}$
$B_2{}^{iii}O_3{}^{ii}$	$N_2{}^{iii}O_3{}^{ii}$	$Sb_2{}^{iii}S_3{}^{ii}$	$Bi_2{}^{iii}S_3{}^{ii}$
$C^{iv}O_2{}^{ii}$	$C^{iv}S_2{}^{ii}$	$Si^{iv}O_2{}^{ii}$	$Si^{iv}S_2{}^{ii}$.

In each case the *valencies* or *bonds* of one element must exactly balance those of the other.

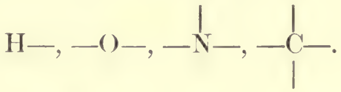
Valency may also be represented as follows: Take the combination of C with H, with Cl substitution:

$$C\left\{\begin{matrix}H\\H\\H\\H\end{matrix}\right. \quad C\left\{\begin{matrix}Cl\\H\\H\\H\end{matrix}\right. \quad C\left\{\begin{matrix}Cl\\Cl\\H\\H\end{matrix}\right. \quad C\left\{\begin{matrix}Cl\\Cl\\Cl\\H\end{matrix}\right. \quad C\left\{\begin{matrix}Cl\\Cl\\Cl\\Cl.\end{matrix}\right.$$

Still another method of representing valencies is by dashes, each dash equalling a bond:

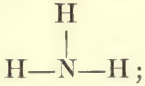
$$H-,\ O=,\ N\equiv,\ C\equiv\!\!-,\ \text{etc.};$$

or thus:



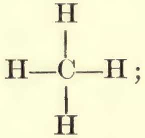
$$H-,\ -O-,\ -\overset{|}{N}-,\ -\underset{|}{\overset{|}{C}}-.$$

Examples of formulæ: From these symbols we derive a system of structural or graphic formulæ, of which the following are good examples:

Hydrogen in free state . H_2 or H—H ;
Oxygen " " " . O_2 " O=O ;
Nitrogen " " " . N_2 " N≡N ;
Water . . . . H_2O " H—O—H ;
Ammonia . . . . . . NH_3 " 

$H-\overset{\overset{H}{|}}{N}-H$;

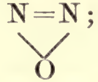
Methane . . . . . CH_4 "



$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-H;$$

Carbon dioxide . . . CO_2 " $O=C=O$;

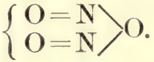
Nitrogen monoxide . . N_2O " $N=N$;



$$\underset{\displaystyle \searrow O \swarrow}{N=N};$$

Cyanogen . . . . . C_2N_2 " $N\equiv C-C\equiv N$;

Nitrogen trioxide . . . N_2O_3 "



$$\left\{\begin{matrix} O=N \\ O=N \end{matrix}\right\rangle O.$$

Unsaturated compounds: In some cases we have formulæ in which the conditions of valency are not satisfied, as in nitrogen dioxide:

$$NO \qquad\qquad -N=O,$$

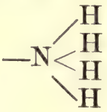
in which one of the valencies, or bonds of affinity, is unsatisfied. Such a compound is called an "*unsaturated compound.*" These compounds unite with other elements with great ease. In the compound cited, NO, it unites with Cl, forming $Cl-N=O$, in which all bonds are satisfied.

Thus it is that molecules of free hydrogen, nitrogen, oxygen, etc., are regarded as saturated compounds; while the free atoms, if they could exist separately, would be "unsaturated." In many chemical changes the elementary atoms are probably set free, but they immediately enter into union with each other to form molecules.

Elements when they are made to assume the condition of atoms are said to be in a "*nascent*" state; and as such the chemical activity is greatly increased.

A **compound radical** is an unsaturated group of atoms acting like an element; as cyanogen, $-C\equiv N$ $\quad CN$;

And ammonium,



$$-N\begin{cases} H \\ H \\ H \\ H \end{cases} \qquad NH_4.$$

The **different kinds of formulæ** are empirical, molecular, rational, and graphic or constitutional.

The *empirical formula* shows the relative number or the simplest ratio of the atoms in the molecule. Thus:

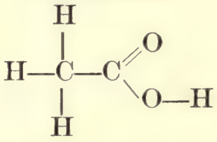
	Molecular formula.	Empirical formula.
Glucose	$C_6H_{12}O_6$	CH_2O;
Acetic acid	$C_2H_4O_2$	CH_2O;
Ethylene	C_2H_4	CH_2.

Molecular formulæ show the exact number of atoms in the molecule, and are obtained from the vapor density, etc.

Rational formulæ separate the molecule into groups, indicating the class of compounds to which the substance belongs. Thus:

	Molecular formula.	Rational formula.
Alcohol	C_2H_6O	C_2H_5OH;
Acetic acid	$C_2H_4O_2$	CH_3COOH;
Aldehyde	C_2H_4O	CH_3COH.

Graphic formulæ endeavor to show the way in which the atoms are joined and arranged within the molecule. Thus:

		Graphic formula.
Acetic acid	$C_2H_4O_2$	

The atoms are connected by lines called *bonds*, which also indicate the atomicity of the elements.

Types: In order to show how compounds decompose, and to aid in recognizing them, their formulæ are written like the formulæ of some well-known compounds, called "types." The types and their structure, with some examples, are given in the following table:

Hydrogen $\left.\begin{matrix}H\\H\end{matrix}\right\rangle$	Hydrogen chloride $\left.\begin{matrix}H\\Cl\end{matrix}\right\rangle$	Water $\left.\begin{matrix}H\\H\end{matrix}\right\rangle O$	Ammonia $\left.\begin{matrix}H\\H\\H\end{matrix}\right\rangle N$	Marsh-gas $\left.\begin{matrix}H\\H\\H\\H\end{matrix}\right\rangle C$
Ethyl hydride $\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\rangle$	Ethyl chloride $\left.\begin{matrix}C_2H_5\\Cl\end{matrix}\right\rangle$	Ethyl alcohol $\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\rangle O$	Ethylamine $\left.\begin{matrix}C_2H_5\\H\\H\end{matrix}\right\rangle N$	Ethyl methane $\left.\begin{matrix}C_2H_5\\H\\H\\H\end{matrix}\right\rangle C$
Diethyl $\left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\rangle$	Acetyl chloride $\left.\begin{matrix}C_2H_3O\\Cl\end{matrix}\right\rangle$	Ethyl ether $\left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\rangle O$	Diethylamine $\left.\begin{matrix}C_2H_5\\C_2H_5\\H\end{matrix}\right\rangle N$	Chloroform $\left.\begin{matrix}H\\Cl\\Cl\\Cl\end{matrix}\right\rangle C$
Acetyl hydride $\left.\begin{matrix}C_2H_3O\\H\end{matrix}\right\rangle$	Benzoyl chloride $\left.\begin{matrix}C_7H_5O\\Cl\end{matrix}\right\rangle$	Acetic acid $\left.\begin{matrix}C_2H_3O\\H\end{matrix}\right\rangle O$	Trimethylamine $\left.\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\right\rangle N$	Alcohol $\left.\begin{matrix}CH_3\\H\\H\\HO\end{matrix}\right\rangle C$
Acetyl methyl $\left.\begin{matrix}C_2H_3O\\CH_3\end{matrix}\right\rangle$		Acetic anhydride $\left.\begin{matrix}C_2H_3O\\C_2H_3O\end{matrix}\right\rangle O$	Acetamide $\left.\begin{matrix}C_2H_3O\\H\\H\end{matrix}\right\rangle N$	Formic acid $\left.\begin{matrix}H\\O=\\HO\end{matrix}\right\rangle C$
Cyanogen hydride $\left.\begin{matrix}NC\\H\end{matrix}\right\rangle$	Cyanogen chloride $\left.\begin{matrix}NC\\Cl\end{matrix}\right\rangle$	Cyanic acid $\left.\begin{matrix}NC\\H\end{matrix}\right\rangle O$	Isocyanic acid $\left.\begin{matrix}OC=\\H\end{matrix}\right\rangle N$	Hydrocyanic acid $\left.\begin{matrix}N\equiv\\H\end{matrix}\right\rangle C$

Knowing that if we replace the hydrogen atom or atoms in an acid a salt is produced, and knowing the valencies of the elements, we are enabled to write a vast number of formulæ which could not possibly be otherwise remembered.

Example.—Write the chemical formula for sulphate of sodium:

——" ic" acid produces ——" ate" salt; hence, sulphate of sodium is produced by replacing the hydrogen atoms in sulphuric acid by atoms of sodium: the valency of H is one, of Na is one; hence H_2SO_4 replaced by Na = Na_2SO_4.

If a dyad element be taken, as calcium, Ca, then calcium sulphate is $Ca = SO_4 \quad CaSO_4$.

In the former case cited, sodium sulphate, still another sulphate may be formed by replacing only one atom of H by Na, yielding a salt, $NaHSO_4$. Such a sulphate is called a *bi* or *acid* sulphate.

Write bisulphate of potassium:

$$H_2'SO_4 \qquad K' \qquad \therefore \qquad KHSO_4.$$

Write *normal* sulphate of potassium:

$$H_2'SO_4 \qquad K' \qquad \therefore \qquad K_2SO_4.$$

Similarly with carbonic acid, H_2CO_3:
Write bicarbonate of sodium:

$$H_2'CO_3 \qquad Na' \qquad \therefore \qquad NaHCO_3.$$

Normal carbonate of sodium:

$$H_2'CO_3 \qquad Na' \qquad \therefore \qquad Na_2CO_3, \text{ etc.}$$

Arrangement of the non-metallic elements according to their valencies: The non-metallic elements are arranged according to their valencies into the following groups:

Monads . . . H, Cl, Br, I, F;
Dyads . . . O, S, Se, Te;
Triads . . . N, P, As, B;
Tetrads . . . Si, C.

INORGANIC CHEMISTRY.

THE NON-METALLIC ELEMENTS.

HYDROGEN. Symbol **H.** Atomic weight 1.

The word hydrogen is derived from *hudor*, water, and *genesis*, generation, meaning "water-former." Hydrogen was named by Lavoisier in 1775, although discovered by Cavendish in 1766.

Occurrence: It is found *free* in volcanic gases, in natural gas from gas-wells, in meteoric iron (occluded), in the atmosphere of the sun as determined by the spectroscope, and in other self-luminous bodies. It is found *combined* in water and in an infinite number of organic compounds, such as coal, petroleum, the tissues of plants and animals, etc.

Preparation:

(1) By decomposing water with metallic sodium; $2H_2O + 2Na = 2NaHO + H_2$;

(2) By decomposing water with an electric current; $2H_2O$ dissociated by electricity into $2H_2 + O_2$;

(3) By decomposing steam with metallic iron; $3H_2O + Fe_2 = F_2O_3 + 3H_2$;

(4) By decomposing acids with metals; $Zn + H_2SO_4 = ZnSO_4 + H_2$.

Physical properties: In a pure state it is a gas, tasteless, odorless, and colorless. Being the lightest substance known, it is taken as the standard of weight for gases. One litre at 0° C. and 760 mm. pressure weighs 0.0896 gram. This weight is called a *crith*. At a temperature of —140° C. and a pressure of 650 atmospheres, to which hydrogen was subjected by M. Pictet, it becomes liquefied.

Hydrogen—chemical properties: It is an inflammable gas, burning with intense heat and a pale blue flame. One gram of burning hydrogen produces heat sufficient to raise 34,462 grams of water from 0° to 1° C. It is not a poisonous gas, but it does not support respiration. Hydrogen burned in the air, thus uniting with the oxygen, forms water: $H_2 + O = H_2O$. It is an effective reducing-agent, capable of withdrawing oxygen from its heated compounds. Hydrogen passed over red-hot copper oxide unites with the oxygen, leaving the copper: $CuO + H_2 = Cu + H_2O$.

There are but **two compounds of hydrogen and oxygen,** The first is water, H_2O, or hydrogen monoxide; the second is the dioxide of hydrogen, H_2O_2, used for bleaching purposes.

All **hydrates** contain both oxygen and hydrogen; as, calcium hydrate, $Ca(OH)_2$; sodium hydrate, NaOH.

The compound radical (OH) is called *hydroxyl.* Every acid contains hydrogen.

Its important compounds with *other elements* are with nitrogen, carbon, sulphur, phosphorus, and numerous others.

CHLORINE. Symbol Cl. Atomic weight 3.55.

Chlorine was discovered by Scheele in 1774, and named from *chloros,* green, on account of its color.

Occurrence: It is an abundant element, and is found combined as chlorides in common salt or sodium chloride, chlorides of the alkalies and alkaline earths, in sea-water, and rarer compounds as mineral cerargyrite or silver chloride.

Preparation: By the action of sulphuric acid on common salt and manganese dioxide:

$$2H_2SO_4 + 2NaCl + MnO_2 = 2(H_2O) + MnSO_4 + NaSO_4 + Cl_2;$$

or, by the action of hydrochloric acid upon manganese dioxide:

$$4(HCl) + MnO_2 = MnCl_2 + 2(H_2O) + Cl_2.$$

Physical properties: It is a greenish-yellow gas of intensely suffocating odor, condensing by cold and pressure to a heavy, yellow liquid.

Chemical properties: Under the influence of light chlorine unites directly and violently with hydrogen, producing hydrochloric acid gas. Cold water absorbs two and one-half times its volume of this gas, forming chlorine-water.

When moist it acts as a bleaching agent by seizing the hydrogen of water and liberating the oxygen, which bleaches by direct oxidation. Finely divided copper, antimony, or arsenic placed in the gas combines, evolving heat and light, to produce a chloride. Hydrogen burns freely in chlorine and chlorine in hydrogen.

Uses: As a bleaching agent for linen, cotton, and paper, and as a disinfectant.

Important compounds: With hydrogen it forms hydrochloric acid, HCl; with oxygen it forms oxides, as hypochlorous oxide, Cl_2O; chlorous oxide, Cl_2O_3; and perchloric oxide, Cl_2O_4.

With oxygen and hydrogen it gives rise to several *oxy-acids:*

Hypochlorous acid, $HClO$; Chlorous acid, $HClO_2$;
Chloric acid, $HClO_3$; Perchloric acid, $HClO_4$.

With nitrogen: NCl_3; and with carbon: C_2Cl_2, C_2Cl_6, C_2Cl_6.

HYDROCHLORIC ACID, OR MURIATIC ACID, HCl.

Preparation: It is produced for commerce by treating a chloride with sulphuric acid. Chloride of sodium is generally employed:

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl.$$

Physical properties: It is a gas very soluble in water, one volume of which at 15° C. will dissolve about 450 volumes of gas, resulting in the liquid acid as it appears in commerce. The pure acid is colorless; the yellowish color often seen is due to impurities of iron.

Chemical properties: It is one of the strongest and most important acids, dissolving many metals with the evolution of hydrogen:

$$Zn + 2HCl = ZnCl_2 + H_2;$$
$$Fe + 2HCl = FeCl_2 + H_2.$$

Aqua regia is a mixture of hydrochloric and nitric acids, sometimes termed royal water. It is important on account of its power to dissolve gold and platinum, two metals which resist the action of any single acid. The acids unite, liberating chlorine:

$$HNO_3 + 3HCl = 2H_2O + NOCl \text{ (nitrosyl chloride)} + Cl_2.$$

Application of chlorine as a bleaching agent: Chlorine passed over slaked lime produces chloride of lime, or hypochlorite of calcium, one of the compounds of chlorine most applicable for bleaching and disinfecting:

$$2CaH_2O_2 + 2Cl_2 = CaCl_2O_2 + 2H_2O + CaCl_2.$$

Bleaching-powder is a mixture of calcium chloride and hypochlorite of calcium. Exposed to heat, air, and moisture it yields hypochlorous acid ($HClO$), and soon breaks up into water, calcium chlorate, and free chlorine.

Detection of chlorides: Any soluble chloride put with silver nitrate gives a curdy precipitate:

$$HCl + AgNO_3 = HNO_3 + AgCl;$$
$$NaCl + AgNO_3 = NaNO_3 + AgCl.$$

The oxides of chlorine are all dangerously explosive.

Preparation of hypochlorous acid, HClO: It is obtained by passing chlorine gas through water containing calcium carbonate (chalk) in suspension:

$$Cl_4 + H_2O + CaCO_3 = CaCl_2 + CO_2 + 2HClO.$$

Properties: An aqueous solution of hypochlorous acid has a yellow color, acid taste, and sweet smell. It is a powerful oxidizing and bleaching agent.

Preparation and properties of chlorous acid, $HClO_2$: It is prepared by reducing chloric acid with arsenic trioxide and nitric acid. The result is a greenish-yellow liquid having strong bleaching and oxidizing properties.

Preparation and properties of chloric acid, $HClO_3$: It is prepared from barium chlorate and sulphuric acid, or by passing chlorine through a solution of potassium hydrate:

$$Ba(ClO_3)_2 + H_2SO_4 = BaSO_4 + 2HClO_3.$$

It is the most important of the series. In the concentrated state it is a syrupy liquid resembling nitric acid in many of its properties. It is a powerful oxidizing agent. A drop of it on paper will cause the latter to ignite.

Compounds and uses of chloric acid: It forms chlorates, among which sodium and potassium chlorates are the most important:

$$NaClO_3 \text{ and } KClO_3.$$

The latter is used for obtaining oxygen in the laboratory.

It also exists in certain explosive mixtures and is used medicinally.

Preparation of perchloric acid, $HClO_4$: It is made by distilling potassium perchlorate with sulphuric acid.

Dropped on wood, paper, or any carbonaceous substance, it combines with explosive violence. In contact with the skin it produces burns.

Preparation and properties of nitrogen trichloride, NCl_3: It is prepared by dissolving chlorine gas in ammonium chloride:

$$NH_4Cl + 6Cl = NCl_3 + 4HCl.$$

This chloride is a very oily, volatile liquid of extremely explosive nature.

BROMINE. Symbol Br. Atomic weight 79.75.

Derivation, discovery, and occurrence: Bromine, from *bromos*, a stink, was discovered by Balard in 1826. It is chiefly found in combination, as bromides of sodium and magnesium in sea-water and in mineral springs; also as the mineral embolite, a bromide and chloride of silver.

Preparation: Any bromide heated with sulphuric acid and manganese dioxide furnishes it for the laboratory. Commercially it is prepared by treating the "mother liquor" of saline solutions, after removing the common salt by crystallization, with sulphuric acid and manganese dioxide, the bromide being distilled and condensed.

Physical properties: Bromine is a dark red liquid with a suffocating and offensive odor. Excepting mercury, it is the only element which is liquid at ordinary temperatures. Specific gravity 3.187; it freezes at —24.5° C. and boils at 63° C.

Chemical properties: It is slightly soluble in water, more freely so in alcohol, and abundantly so in ether. An aqueous solution, bromine-water, has bleaching properties. It stains organic substances yellow.

Bromine is a commercial product. In 1892 the United States produced 379,480 pounds.

Important compounds:

Hydrobromic acid, HBr; Bromic acid, $HBrO_3$;
Hypobromous acid, $HBrO$; Perbromic acid, $HBrO_4$.

Hydrobromic acid—preparation and properties: Phosphorus and bromine in contact with water produce the acid:

$$P_2 + Br_6 + 6H_2O = 6HBr + 2H_3PO_3.$$

It is a colorless, strongly acid gas, of pungent odor, very soluble in water, producing a red solution.

Hypobromous acid—preparation and properties: It is obtained by the action of bromine-water upon mercuric oxide. It is a straw-colored liquid having bleaching properties, and decomposes at 60° C.

Bromic acid—preparation and properties: Produced by chlorine gas in bromine-water:

$$Br_2 + 5Cl_2 + 6H_2O = 2HBrO_3 + 10HCl.$$

Strong acid reaction and bleaching properties; decomposes at 100° C.

IODINE. Symbol **I.** Atomic weight 126.53.

Discovery and occurrence: Courtois discovered iodine in 1811. It exists in a marine plant, sea-water, and saline mineral springs, and in deposits of sodium nitrate (Chile saltpetre) in Chile.

Preparation: In the laboratory it is made by heating any iodide with sulphuric acid and manganese dioxide:

$$2KI + 2H_2SO_4 + MnO_2 = K_2SO_4 + MnSO_4 + 2H_2O + I_2.$$

The commercial methods use the ashes of sea-weed for the iodide, which may exist as sodium, potassium, and magnesium iodide.

Physical properties: Bluish-black scales having a metallic lustre; it yields dense violet vapors when heated. Specific gravity 4.95. Melts at 115° C.; boils at 200° C.

Chemical properties: Practically iodine is insoluble in water, but easily soluble in alcohol, making the tincture of iodine. It is soluble in potassium iodide solution. With starch it gives a blue color, each being a test for the other.

Important compounds of iodine: They are:

Hydriodic acid, HI; Iodic acid, HIO_3;
Periodic acid, HIO_4; Pentoxide of iodine, I_2O_5; and
Nitrogen iodide, NI_3.

The *pentoxide* is the result of direct oxidation of iodine.

Properties of hydriodic acid: Sulphuretted hydrogen passed through water containing iodine in suspension produces this acid as a heavy, colorless gas within the water. It is used in photography:

$$2I + H_2S = 2HI + S.$$

Iodic and periodic acids resemble the corresponding compounds of chlorine.

Nitrogen iodide: It is formed by the action of ammonium hydrate upon iodine. The slightest touch is sufficient to detonate the compound, NI_3, which separates into N and I_3.

FLUORINE. Symbol F. Atomic weight 19.

Occurrence: It is a constituent of many minerals, such as fluorite, calcium fluoride, CaF_2; cryolite, sodium and aluminium fluoride, $6NaF,Al_2F_6$; and apatite, $3Ca_3P_2O_8 + Ca(Cl,F)_2$. It never occurs free.

Properties: Fluorine is a colorless gas, extremely corrosive, possessing a chemical activity greater than any of the other elements. It is the only element that will not unite with oxygen.

An *important compound* is **hydrofluoric acid**, HF, prepared from calcium fluoride and sulphuric acid:

$$CaF_2 + H_2SO_4 = CaSO_4 + 2HF.$$

Properties: This is a very volatile liquid, extremely corrosive, uniting violently with water. The dilute acid will attack the silica of glass, and is, therefore, used for etching small glass articles, like thermometer-stems, which could not be readily handled in a sand-blast. It also causes deep ulcers when touched to the skin. It is stored in gutta-percha bottles.

OXYGEN. Symbol **O.** Atomic weight 16.

Derivation of name, discovery, and occurrence: It is derived from *oxus*, acid, and *genesis*, generation, meaning acid-former. It was at one time supposed to be the chief element of all acids, therefore erroneously named. Its first name was "dephlogisticated air." It was discovered by Priestley in England, and independently by Scheele in Sweden in 1774.

It is found *free* as one-fifth of the atmosphere, and in solution in water. *Combined*, it forms by weight about eight-ninths of all water, and occurs in a variety of oxides, acids, and salts. It exists in plant and animal substances, the crust of the earth, and in the sun. It forms about 45 per cent. of the earth's crust.

Preparation: Oxygen is most readily prepared by heating potassium chlorate and collecting the gas by displacement. The decomposition takes place at a lower temperature if one part of manganese dioxide is added to four parts of potassium chlorate:

$$2KClO_3 + 2MnO_2 = 2MnO_2 + 2KCl + 3O_2.$$

(2) By heating mercuric oxide:

$$2HgO = Hg_2 + O_2 \text{ (Priestley's method).}$$

(3) By the decomposition of water by electricity.

(4) By numerous other processes; as:

$$3MnO_2 + \text{heat} = Mn_3O_4 + O_2 \text{ (Scheele's method).}$$

Physical properties: Oxygen is a colorless, odorless, tasteless gas, liquefiable by cold and pressure. When the pressure is relieved the heat absorbed by evaporation of part of this liquid serves to solidify the remainder.

Chemical properties: (1) Oxygen unites directly with all the elements except fluorine. Its activity in attacking decaying animal and vegetable matter, forming harmless compounds, renders it a great disinfectant and purifier.

(2) It is soluble in water to the extent of 4 per cent. The dissolved oxygen permits life of fishes and other water-breathing animals, and purifies the waters on the earth's surface.

(3) It is the supporter of combustion and life. The combustion may be slow, or rapid enough to produce heat and light. The products of all complete combustion of hydrocarbons are CO_2 and H_2O. The readiness with which oxygen unites with wood, coal, petroleum, and other substances furnishes us with heat and light. The blood of all animals contains certain substances which are oxidized through some type of breathing apparatus, the heat of combustion generally serving to elevate the temperature of the body. In this manner the oxygen necessary for animal life is converted into carbon dioxide, CO_2, which is the requisite for plant existence. The plant absorbs the CO_2 through its pores, and by action of sunlight and chlorophyl (the green coloring-matter of plants) the CO_2 is decomposed into carbon and oxygen, the carbon being assimilated by the plant structure and the oxygen returned to the atmosphere.

Oxidation and combustion are carried on very energetically in an atmosphere of oxygen: sulphur and phosphorus burn with intense light, and heated iron or steel wire will burn with sufficient heat to melt the wire.

The oxides: These are named monoxide, dioxide, trioxide, tetroxide, pentoxide, and sesquioxide, according to the ratio of oxygen with an element; as

Nitrogen monoxide, N_2O ; Nitrogen tetroxide, N_2O_4 ;
" dioxide, N_2O_2 ; " pentoxide, N_2O_5.
" trioxide, N_2O_3 ;

(2) They are also called acid, basic, or neutral, according to the reactions which they have.

Ozone: It is oxygen intensified in activity and modified in its nature. It was discovered by Schönbein, of Basle, in 1840. It is found in the air, especially after electric disturbances. (1) It may be *prepared* by the passage of a current of electricity through a tube containing oxygen. (2) By slow oxidation of phosphorus, ether, and turpentine:

$$P_2 + 3O_2 = P_2O_3 + O_3;$$

Phosphorus burned in air combines as a pentoxide:

$$2P_2 + 5O_2 = 2P_2O_5;$$

(3) By the action of sulphuric acid on barium dioxide:

$$3H_2SO_4 + 3BaO_2 = 3BaSO_4 + 3H_2O + O_3.$$

Chemical and physical properties: Ozone is a gas of peculiar metallic odor, insoluble in water and in solutions of acids or alkalies. By heat it reverts to the less active oxygen. It is a powerful oxidizing agent, corroding cork, rubber, and other organic substances, and rapidly oxidizing iron, silver, and copper, besides possessing potent bleaching and disinfecting properties.

The test for ozone: It decomposes potassium iodide, liberating iodine, which may be detected by starch solution, the iodine turning the solution blue.

Water.

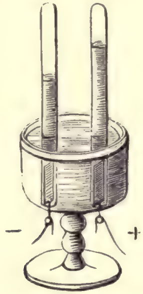
Composition: Water is the monoxide of hydrogen, H_2O. It always contains impurities, either in solution or in suspension, or in both.

Impurities in water: Rain-water contains gaseous impurities washed from the atmosphere, together with traces of solid matter. River-, spring-, well-, and lake-waters contain a variety of mineral substances dissolved from the soil. Sea-water, salt lakes, and mineral springs contain saline substances in large quantities. Effervescent waters are either naturally or artificially charged with carbon dioxide gas, CO_2. Water containing much lime in solution is called "hard" water; if little or no lime is present, the water is said to be "soft." Perfectly pure water is tasteless, and palatable only after aëration. Suspended impurities may be separated from water by filtration; dissolved impurities, by distillation.

Synthetic preparation of water: By passing an electric spark through a mixture of oxygen and hydrogen gas enclosed in a eudiometer the gases unite to form water. The apparatus consists of a strong glass tube, closed at one end and supported over a trough of mercury, into which the open end projects. It is also adjusted to receive the electric spark. Water is always a product of combustion whenever the substance burned contains hydrogen.

Decomposition of water: The two constituent gases of water may be obtained by passing an electric current through a vessel of water and collecting the gases which form and escape from the two poles of the battery.

FIG. 1.



Analysis for sanitary and industrial purposes disregards the proportion of oxygen and hydrogen, and deals only with dissolved impurities.

Analysis of the salts of ocean water: The analysis of 1000 grains of water from the British Channel gave the following:

Water	964.745;
Sodium chloride	27.059;
Potassium chloride	0.766;
Magnesium chloride	3.666;
Magnesium bromide	0.029;
Magnesium sulphate	2.296;
Calcium sulphate	1.406;
Calcium carbonate	0.033;
Traces of iodine and ammoniacal salts	
	100.000.

Classification of mineral-waters: (1) *Saline:* Containing sodium chloride (common salt); as the sea, salt springs, and lakes; sodium sulphate—Glauber's salt, springs at Ems.

(2) *Alkaline:* Containing bicarbonate of sodium or lithium—Vichy, Seltzer, and apollinaris.

(3) *Acid:* Sulphuric and hydrochloric acid, as at Rio Vinagre.

(4) *Acidulous:* Carbonic acid and bicarbonates of lime and magnesium—High Rock Spring, Saratoga.

(5) *Chalybeate:* Iron bicarbonate—Saratoga.

(6) *Alum:* Aluminium and potassium sulphate (alum)—Virginia.

(7) *Borax:* Sodium borate (borax)—California and Italy.

(8) *Sulphur:* Hydrogen sulphide (sulphur spas)—Virginia, Arkansas, and Harrowgate.

(9) *Silicious:* Hot geysers—Iceland and Yellowstone Park; generally alkaline.

Water containing forty grains or less of mineral matter per gallon is termed sweet or fresh. An excess of amount renders the water a mineral water.

Analysis of Croton water: Croton water contains the following mineral substances in solution: Parts in 100,000:

Calcium bicarbonate, $CaH_2(CO_3)_2$	4.53;
Magnesium bicarbonate, $MgH_2(CO_3)_2$	3.25;
Silicon dioxide, SiO_2	1.05;
Sesquioxide of iron, Fe_2O_3	trace;
Sesquioxide of aluminium, Al_2O_3	trace;
Calcium sulphate, $CaSO_4$	0.26;
Sodium sulphate, Na_2SO_4	0.44;
Potassium sulphate, K_2SO_4	0.30;
Sodium chloride, $NaCl$	0.68;
Organic matter	1.13;
	11.64.

The physical properties of water: Pure water in small quantities is transparent, tasteless, odorless, and colorless. In masses it assumes a bluish tint. It may exist in the solid, liquid, or aëriform state. Ordinarily it freezes at 0° C., boils at 100° C., and evaporates at all temperatures. It is practically incompressible, but contracts regularly from the boiling-point to about 4° C., its maximum density; then expands until 0° C. is reached, at which point it undergoes further and sudden expansion to become ice. It is this expansive force which ruptures water-vessels and water-pipes and disintegrates rocks. Because ice is expanded-water solidified, it is lighter than the same volume of water, and therefore floats. If water had its maximum density at the freezing-point, ice would form at the bottom of rivers and lakes and thus destroy fish and other aquatic life. When vapor is suddenly chilled, snow is formed.

Chemical properties of water: It is the best solvent known, and its solvent power for most solid substances increases with its temperature. For this reason, hot saturated solutions on cooling deposit their excess of solid matter in the form of crystals.

Water also dissolves gases, but with a power increasing with pressure and a diminution of temperature.

Some solids, like common salt, dissolve equally well in hot or cold water.

The freeing of gas from water: (1) By exposure under exhaust-pump;

(2) By heating to boiling-point of water;

(3) By freezing the water, thus eliminating the gas. This is shown by the presence of air-bubbles in ice, which consist of the air dissolved from the atmosphere and set free by solidification.

Pure water dissolves gases more copiously than water containing salts in solution, except in some cases where the dissolved salt forms a chemical combination with the gas absorbed.

Standards based on the properties of water:

(1) *Standard of weight:*

1 cubic centimetre of water at 4° C. weighs 1 gramme.

(2) *Standard of temperature:*

The centigrade thermometer has zero-point at temperature of freezing and 100° at temperature of boiling water. Reaumur has zero-point at temperature of freezing and 80° at temperature of boiling. Fahrenheit has 32° at temperature of freezing and 212° at temperature of boiling.

(3) *Standard of amount of heat:*

The heat-unit is called a calorie.

The French unit is the amount of heat necessary to raise 1 kilogram of water 1° C. The British heat-unit (B. H. U.) is the amount of heat necessary to raise 1 pound of water 1° F.

(4) *Standard of specific gravity:*

Solids and liquids are referred to water as the unit of comparison.

If the substance is twice as heavy as water, bulk for bulk, its specific gravity is said to be 2, etc.

(5) *Standard of specific heat:*

The specific heat of water being 1, the specific heat of gases, liquids, and solids is referred to it.

Action of water on oxides, and formation of hydroxides: Water acts on many oxides, both basic and acid, with great energy and considerable evolution of heat, producing compounds called "*hydroxides,*" which contain hydrogen and oxygen not actually existing as water, the elements undergoing a different arrangement in combining:

$K_2O + H_2O = 2KOH$, potassium hydroxide (potash);
$CaO + H_2O = CaO_2H_2$, calcium " (slaked lime);
$SO_3 + H_2O = SH_2O_4$, sulphur " (sulphuric acid);
$P_2O_5 + H_2O = 2PHO_3$ phosphorous " (metaphosphoric acid).

In many of these compounds the elements of water are retained with great tenacity, requiring a high temperature to expel them. Calcium hydroxide, for example, requires a red heat to convert it into anhydrous calcium oxide (quicklime); and the hydroxides of potassium, barium, sulphur, and phosphorus cannot be dehydrated by heat alone.

In other cases water appears to combine with substances—salts, for example—without alteration of atomic arrangement. These bodies are called hydrates. This "water" is easily expelled by heat, mostly at 100°–120° C.

Water of crystallization: When water combines in the manner mentioned in the preceding paragraph it is called *water of crystallization.* This has a marked influence on the crystalline form of the substance.

Many salts combine with different quantities of water, according to the temperature at which they separate from solution. Thus: sodium carbonate, Na_2CO_3, crystallizes from solution at ordinary temperatures in oblique rhombic prisms containing 10 molecules of water, $Na_2CO_3,10H_2O$; whereas at a higher temperature it crystallizes with 5 or 8 molecules of water, $Na_2CO_3,5H_2O$ or $Na_2CO_3,8H_2O$. From a boiling solution it forms rectangular plates having but 1 molecule of water, Na_2CO_3,H_2O.

Efflorescence: In some cases the water of crystallization is so feebly combined that it gradually separates when the substance containing it is exposed to dry air at ordinary temperatures. This separation is accompanied by loss of crystalline character, the substance falling to powder. This change is called *efflorescence*, and is strikingly shown by crystals of alum and ferrous sulphate.

Deliquescence: Many substances which are very soluble in water attract water from moist air in such quantities as to form a solution. This change, which is shown by calcium chloride and potassium hydroxide, is called *deliquescence*.

Hydrogen dioxide: Its **formula** is H_2O_2. Discovered by Thenard in 1818.

Preparation: The action of sulphuric acid on barium dioxide forms hydrogen dioxide:

$$BaO_2 + H_2SO_4 = BaSO_4 + H_2O_2.$$

Properties and uses: Ordinarily it is a colorless, odorless liquid, possessing remarkable bleaching properties. It may be concentrated to a specific gravity of 1.45. Heat easily decomposes it into water and oxygen. It is used as an oxidizing and bleaching agent. It brightens old paintings and whitens the skin and hair.

SULPHUR. Symbol S. Atomic weight 32.

Occurrence: It occurs free in volcanic districts, notably in Sicily and Southern Italy.

It occurs combined as *sulphides* of the common metals—

iron, copper, lead, zinc, mercury, silver, arsenic, antimony, etc.

It occurs combined as *sulphates* of calcium (gypsum), barium (barite), strontium (celestite), magnesium (Epsom salt), etc.

It occurs in an unoxidized condition in animal and vegetable tissues.

The volatile oils of garlic, mustard, and horseradish owe their odor to sulphur compounds.

Stains on silverware in contact with eggs, onions, etc., are due to sulphur forming sulphide of silver.

Preparation: (1) If the ore is nearly pure, the sulphur is melted and the earthy matter removed.

(2) When the material contains but little sulphur, it is heated in retorts and the sulphur distilled.

The commercial forms are lump, stick or rolled, and lac sulphur. Lac or milk sulphur is chemically prepared by adding hydrochloric acid to calcium sulphide. It is used medicinally.

Physical properties: (1) Sulphur is a yellow, brittle, odorless, tasteless solid, capable of allotropic forms. Its atomic weight is 32. Below 500° C. its vapor density is 96; between 800° and 1000° C. its vapor density becomes 32, or normal. Hence at ordinary temperatures the sulphur molecule is S_6, but at high temperatures it becomes S_2. It mets at 114.5° C. and boils at 448° C.

(2) Heated to 230° C. it becomes thick and dark; at 250° C. it regains its fluidity, and if poured into water it assumes a brown color and putty-like consistency. This is known as plastic sulphur, and is much used for taking impressions. This plastic form reverts to ordinary sulphur.

Roll sulphur rubbed with wool or hair excites negative electricity.

(3) The condensed vapors of heated sulphur are known as flowers of sulphur.

Chemical properties: Sulphur unites directly with most of the metals by the application of heat, thus making sulphides. It is insoluble in water or alcohol, but soluble in carbon disulphide, benzine, oil of turpentine, heavy petroleum oils, etc.

The Compounds of Sulphur.

Hydrogen monosulphide, H_2S: Also called hydrosulphuric acid; sulphydric acid; sulphuretted hydrogen.

Occurrence: It is a frequent product of the putrefaction of organic matter, whether animal or vegetable. It also occurs in certain mineral springs, as at Harrowgate.

Preparation: Dilute sulphuric acid and iron monosulphide produce hydrogen sulphide:

$$FeS + H_2SO_4 = FeSO_4 + H_2S.$$

Properties: It is a colorless gas with an odor like putrid eggs. It is also a powerful narcotic. Burning in oxygen, it gives a blue flame and produces water and sulphur dioxide. It possesses the properties of an acid, and turns blue litmus red.

Uses: In the laboratory it is a valuable reagent, precipitating many metals from their solutions and giving characteristics of color, solubility, or other identifying properties.

Hydrogen persulphide is an unstable compound, supposed to be H_2S_2. It dissolves phosphorus and iodine, forming a phosphorous sulphide and hydrogen iodide respectively, with the evolution of H_2S.

Sulphur monochloride (SCl or S_2Cl_2)—preparation: It is obtained by passing dry chlorine gas into a retort into which sulphur is sublimed at a red heat. The chloride distils over and is condensed into a mobile, reddish-yellow liquid of disagreeable odor, fuming strongly in air.

It dissolves in carbon disulphide, alcohol, and ether. Ether, when saturated with sulphur at ordinary temperatures, forms a clear, yellow liquid containing 66.7 per cent. of sulphur. The solution of this in crude benzol is used in vulcanizing or sulphurizing caoutchouc.

Dichloride of sulphur, SCl_2, is prepared by passing dry chlorine to saturation into the monochloride cooled by ice and salt, and expelling the excess of chlorine by a stream of carbonic acid gas. It is a deep red liquid.

Tetrachloride of sulphur, SCl_4: These two chlorides are unimportant.

Sulphur and **bromine** combine, forming a brownish-red liquid, probably S_2Br_2.

Sulphur and **iodine** form various combinations, the most important of which is S_2I_2, a blackish-gray crystalline mass.

Oxides of sulphur: They are sulphur dioxide and sulphur trioxide:

$$SO_2 \text{ and } SO_3.$$

Both unite with water and metallic oxides, forming acids and salts.

Sulphur dioxide is prepared either by burning sulphur in the air or in oxygen, or by heating sulphuric acid and copper together. It is the only product of the combustion of sulphur in oxygen.

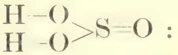
It is a colorless gas, with the odor of burning sulphur, irrespirable, and a non-supporter of combustion. Sulphur thrown on the fire in stove or grate produces this gas, and thus extinguishes the fire of a burning flue or chimney. Cold water will dissolve thirty times its volume of this gas. It has both bleaching and disinfecting properties. Straw and woollen goods are whitened when subjected to its action. It is also used in the manufacture of sulphuric acid.

Sulphur trioxide: The simplest method for its production is to heat Nordhausen (pyro) sulphuric acid and collect the trioxide as silky, white crystals, which readily dissolve by the absorption of moisture. It also dissolves in water to form sulphuric acid:

$$H_2S_2O_7 + \text{heat} = H_2SO_4 + SO_3.$$

Oxy-acids of sulphur:

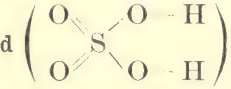
(1) Hyposulphurous acid	H_2SO_2;
(2) Sulphurous acid	H_2SO_3;
(3) Sulphuric acid	H_2SO_4;
(4) Pyrosulphuric acid	$H_2S_2O_7$;
(5) Thiosulphuric acid	$H_2S_2O_3$;
(6) Dithionic acid	$H_2S_2O_6$;
(7) Trithionic acid	$H_2S_3O_6$;
(8) Tetrathionic acid	$H_2S_4O_6$;
(9) Pentathionic acid	$H_2S_5O_6$.

Hyposulphurous acid,  $\begin{matrix}H-O\\H-O\end{matrix}>S=O$: It is obtained by the action of zinc and sulphurous acid, and exists as a yellow liquid having reducing and decolorizing properties. Its salts are called *hyposulphites.*

Sulphurous acid: Sulphur dioxide united with water gives the acid:

$$H_2O + SO_2 = H_2SO_3.$$

It has bleaching properties. Its salts are called *sulphites.*

Sulphuric acid  —**preparation**: The method employed is to unite sulphur dioxide, nitrogen tetroxide, and water:

$$SO_2 + H_2O = H_2SO_3;$$
$$H_2SO_3 + NO_2 = H_2SO_4 + NO.$$

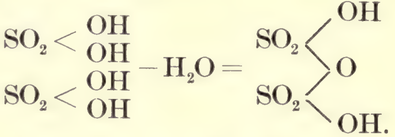
Sulphur is burned in a suitable furnace and the SO_2 gas carried to a leaden chamber supplied with steam and air. The SO_2 is absorbed by the condensing vapors. This new compound of sulphurous acid then takes another atom of oxygen, which is furnished by the nitrogen tetroxide, NO_2, which is produced and admitted to the chamber, forming products shown by the equation. The liquid when drawn off and concentrated by evaporation becomes the sulphuric acid of commerce. The nitrogen tetroxide fumes are produced by the action of sulphuric acid on a nitrate. In place of burning sulphur, iron sulphide is often roasted. Sulphuric acid is often called *oil of vitriol.*

Properties: Sulphuric acid is a colorless, oily liquid (specific gravity 1.85), intensely acid, and quickly destroying organic matter, which it chars. Boils at 327° C.; freezes at —26° C. With metallic oxides it readily forms sulphates. Attacking the skin, it burns painfully. It decomposes carbonates with effervescence.

Test for sulphuric acid: With barium chloride it forms a white precipitate of insoluble barium sulphate:

$$BaCl_2 + H_2SO_4 = BaSO_4 + 2HCl.$$

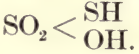
Pyrosulphuric acid: Withdrawing one molecule of water from two molecules of sulphuric acid, the compound $S_2O_7H_2$ results (pyrosulphuric acid):



This acid is contained in the so-called fuming or Nordhausen sulphuric acid.

It is a thick, oily, strongly fuming liquid.

Thiosulphuric acid: This acid may be considered as sulphuric acid in which the oxygen of an hydroxyl group is replaced by sulphur,



$$SO_2<\begin{matrix}SH\\OH.\end{matrix}$$

It is generally known as hyposulphurous acid. Its sodium salt is used in photography to dissolve silver chloride, and as an "antichlor" to remove traces of chlorine from bleached goods.

SELENIUM. Symbol Se. Atomic weight 79.

Occurrence: Discovered by Berzelius in 1817, it is associated with sulphur in certain rare minerals; also with copper, lead, silver, and mercury.

Properties: Like sulphur, selenium exists in allotropic forms, and makes several compounds:

(1) It is a grayish-black solid, insoluble in carbon disulphide;

(2) It is a brick-red powder, soluble in carbon disulphide, from which it crystallizes.

It has but few *uses*, and these are applied in electricity.

Its known *compounds* correspond to those of sulphur. They are not especially important.

TELLURIUM. Symbol Te. Atomic weight 125.

Occurrence: It is found free; also combined with gold, silver, bismuth, lead, and rare minerals.

Properties: Tellurium is a silvery-white solid, with a clear metallic lustre, burning in the air with a blue flame. It is brittle and a poor conductor of heat and electricity. Its compounds are similar to those of sulphur.

NITROGEN. Symbol N. Atomic weight 14.

The *word* is derived from *nitron*, nitre, and *geneses*, production. Rutherford discovered it in 1772.

Occurrence: (1) It exists free in the atmosphere, of which it constitutes four-fifths.

(2) Combined, it is found in all animal and plant life and in some of the resultants of their decomposition, such as coal, peat, and lignite; also in ammonia gas emanating from decaying matter.

As mineral nitrates it is abundant, the most important being saltpetre, KNO_3, and Chile saltpetre, $NaNO_3$.

Production: (1) By exhausting the oxygen from the air by burning phosphorus under a bell-jar held over water. The phosphoric acid thus formed will be dissolved by the water, leaving the nitrogen in the jar:

$$5(4N_2 + O_2) + 4P = 2P_2O_5 + 20N_2.$$

(2) By passing air over red-hot copper confined in a suitable vessel. The copper will combine with the oxygen, making copper oxide, and leave the nitrogen in the vessel:

$$5(4N_2 + O_2) + 10Cu = 10CuO + 20N_2.$$

Properties: It is a colorless, tasteless, odorless gas, a nonsupporter of combustion, and slightly soluble in water.

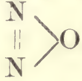
Nitrogen is assimilated by plants in the form of ammonia, and as various nitrates and nitrites.

Some compounds of nitrogen:

Oxides: N_2O, monoxide;
N_2O_2 or NO, dioxide;
N_2O_3, trioxide;
N_2O_4 or NO_2, tetroxide;
N_2O_5, pentoxide.

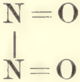
Acids: HNO, hyponitrous acid;
HNO_2, nitrous acid;
HNO_3, nitric acid.

Salts: Nitrates and nitrites.
Nitrogen and hydrogen, NH_3, ammonia;
Nitrogen and carbon, CN, cyanogen (see Carbon).
Organic compounds (see Organic Chemistry).

Nitrogen monoxide,  $\begin{matrix}N\\ \|\\ N\end{matrix}\!\!>\!O$: This gas, often called nitrous oxide or *laughing-gas,* is *prepared* by heating ammonium nitrate and collecting the gas:

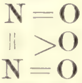
$$NH_4NO_3 + \text{heat} = 2H_2O + N_2O.$$

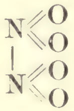
It is a colorless, odorless gas, of sweet taste, liquefiable, and readily soluble in water, forming hyponitrous acid. On account of the ease with which it parts with its oxygen, it supports combustion. Inhaled in small quantities it produces exhilarating effects; hence the name "laughing-gas." Prolonged inhalation produces unconsciousness with complete insensibility to pain. This effect is temporary and not followed by depression. When carefully prepared it is used as an *anæsthetic*, chiefly by dentists.

Nitrogen dioxide,  $\begin{matrix}N=O\\ |\\ N=O\end{matrix}$: N_2O_2, sometimes written NO, is obtained by the action of nitric acid on copper filings:

$$8HNO_3 + 3Cu = N_2O_2 + 3Cu(NO_3)_2 + 4H_2O.$$

It is a colorless, transparent gas, having a suffocating odor. Exposed to the air, it combines with two more atoms of oxygen, forming nitrogen tetroxide. This gas is produced whenever metals are oxidized or dissolved by nitric acid.

Nitrogen trioxide,  $\begin{matrix}N=O\\ \|\;\;>O\\ N=O\end{matrix}$: This is prepared by adding four volumes of N_2O_2 (or NO) to one volume of O and cooling to —18° C.; a blue liquid, N_2O_3, is obtained.

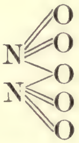
Nitrogen tetroxide,  $\begin{matrix}N\begin{smallmatrix}\diagup O\\ \diagdown O\end{smallmatrix}\\ |\\ N\begin{smallmatrix}\diagup O\\ \diagdown O\end{smallmatrix}\end{matrix}$: (*a*) The tetroxide (also called peroxide), N_2O_4 or NO_2, is obtained by decomposing lead nitrate by heat:

$$Pb(NO_3)_2 + \text{heat} = PbO + O + N_2O_4;$$

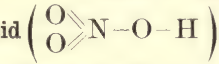
The N_2O_4 thus produced is condensed to a *solid* form.

(*b*) By the action of nitric acid on metals the gaseous form is produced.

At very low temperatures it forms colorless prismatic crystals. As a liquid, it has a greenish-yellow tint; as a gas, it is deep red in color.

Nitrogen pentoxide,  : The pentoxide or nitric anhydride is obtained by the action of chlorine gas on silver nitrate. It is crystalline and colorless and easily decomposed by water, forming nitric acid:

$$N_2O_5 + H_2O = 2HNO_3.$$

Nitric acid  $\left(\begin{matrix}O\\O\end{matrix}\!>N-O-H\right)$**—occurrence**: It is a product of decomposing animal matter containing nitrogen. In the presence of weak alkaline bases, nitrates are formed of these bases. Nitre beds are thus produced, notably as KNO_3, saltpetre in India, and as $NaNO_3$, Chile saltpetre in Chile.

Preparation: Nitric acid is always produced by treating some nitrate, usually sodium or potassium, with sulphuric acid. If much heat is employed, the reaction is:

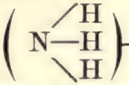
$$2NaNO_3 + H_2SO_4 = 2HNO_3 = Na_2SO_4.$$

Properties: When pure, **nitric acid** is a colorless liquid with suffocating odor, sour taste, and extremely corrosive tendencies. Specific gravity 1.5. It attacks all ordinary metals, except gold and platinum, and thus derives its name "aqua fortis." It turns wool and the skin yellow, oxidizes readily, and forms nitrates with all the regular metals except arsenic and tin.

Its **use** is extensive and important.

(*a*) *Medicinally*, it is used as a caustic and in compounding medicines.

(*b*) *In the arts*, it is used in refining metals, engraving copper plates, and in the production of nitroglycerin, gun-cotton, aniline dyes, etc.

Ammonia  —**occurrence**: In minute quantities it is found in the air, juices of plants, all mineral waters, and therefore distributed over the earth's surface.

Preparation: (1) By heating an ammonium salt with an alkaline substance:

$$2NH_4Cl + Ca(OH)_2 = CaCl_2 + 2NH_3 + 2H_2O;$$

(2) By reducing nitric acid with zinc and caustic potash;

(3) By putrefactive changes in nature;

(4) By the destructive distillation of animal and vegetable matter. When illuminating-gas is obtained by distilling coal, ammonia is one of the waste-products, and this is the commercial source of the gas.

Physical properties: It is a colorless gas, of pungent odor, easily liquefied, for which property it is used in the manufacture of artificial ice, the principle being that when a liquid evaporates heat is absorbed from surrounding objects.

Chemical properties: Ammonia is abundantly soluble in water, the aqueous solution being the common aqua ammonia or ammonium hydrate—$NH_4(OH)$. It is strongly alkaline, neutralizing the strongest acids and forming salts with them. It differs from alkalies in the fact that it will not saponify fats; it emulsifies them. Ammonia was originally produced near the temple of Ammon, hence the name. It was also obtained by distilling the horns and hoofs of the hart, thus giving rise to the name hartshorn.

Nitrogen chloride: NCl_3 is a very volatile vapor, irritating to the eyes. It explodes with fearful violence if brought into contact with almost any combustible material at ordinary temperatures.

Nitrogen iodide: Iodine scales saturated with ammonia produce a dry powder, NI_3 or NHI_2, which with the slightest touch gives up its nitrogen explosively.

The atmosphere—*composition :*

By weight:		By volume:	
Nitrogen,	77	Nitrogen,	79.19
Oxygen,	23	Oxygen,	20.81
	100		100.00

It also contains variable quantities of—

Aqueous vapor, depending on the temperature ;

Ammonia, traceable ;

Solid matter (cosmical and terrestrial dust) ;

Carbonic dioxide, 3.7 to 6.2 volumes in 10,000 volumes of air.

The weight of air : One litre of pure air at 0° C. and 760 mm. pressure weighs 1.29366 grams, or about 14.42 times as heavy as hydrogen.

Proof that air is a mixture and not a chemical compound :

1st. The composition is not absolutely constant, as would be the case if it were a chemical compound ;

2d. When air is absorbed by water, then expelled, the ratio of the nitrogen and oxygen is not the same as in the original air ;

3d. Air produced by mixing proper quantities of oxygen and nitrogen is not attended by any chemical phenomena.

PHOSPHORUS. Symbol **P.** Atomic weight 31.

The word is derived from *phos*, light, and *pherein*, to bear. Phosphorus was discovered by Brandt, in Hamburg, in 1669.

Occurrence : In combination as phosphates phosphorus occurs in ancient unstratified rocks and modern lava. As a result of their disintegration it occurs in fertile soils, from which it passes into the organisms of plants and ultimately into the bodies of animals subsisting on vegetable life. The composition of human bones is nearly half calcium phosphate, which gives them firmness and inflexibility. The most important mineral is apatite, $Ca(PO_4)_2 + \frac{1}{3}Ca(FCl)_2$. It is extensively used as the source of fertilizers. Phosphates of lead, copper, iron, manganese, aluminium, magnesium, and of the rarer elements also occur.

Production: By treating calcium phosphate with sulphuric acid a precipitate of calcium sulphate and a solution of acid calcium phosphate is obtained. This solution is evaporated to a syrupy consistency, after which carbon is added and the whole subjected to distillation. The phosphorus is reduced and distilled, being caught under water to prevent oxidation.

Physical properties: *Ordinarily*, it exists as a yellowish-white, waxy solid, with the odor of a burning match. Its specific gravity is 1.837. It meets at 44° C. and boils at 290° C., giving a vapor density of 62, which is double its atomic weight, showing that a phosphorus molecule is composed of 4 atoms. Exposed to air at a low temperature it oxidizes slowly, emitting a feeble light, whence its name.

Chemical properties: (1) *Ordinary* phosphorus is extremely poisonous. It oxidizes readily, and must, therefore, be kept under water. It is highly inflammable, and on this account is used in the manufacture of matches. Ignited in contact with the skin, its burns are deep and painful. It is insoluble in water, slightly soluble in olive oil and ether, but freely soluble in carbon disulphide, yielding a dangerous combustible substance.

(2) *Amorphous or allotropic:* When common phosphorus is heated to 240° C. in an atmosphere free from oxygen, it becomes converted into an extraordinary allotropic form, possessing special properties. It is an odorless, non-luminous, dark red, opaque powder, insoluble, and not poisonous, and has a specific gravity of 2.11. Heated to 260° F., it reverts to the ordinary phosphorus.

(3) Bemsen and Keiser have recently described another form, analogous to flowers of sulphur. It is produced by distilling common phosphorus in an atmosphere of hydrogen, which yeilds a white, flaky substance.

(4) A black variety has also been described by Thénard.

Compounds of Phosphorus.

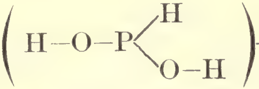
Phosphorous pentoxide: It is produced when phosphorus is burned in an excess of air:

$$2P_2 + 5O_2 = 2P_2O_5.$$

It is a white powder, absorbing water in varying proportions to produce acids:

$$\begin{aligned}
&P_2O_5 + H_2O = H_2P_2O_6 = 2HPO_3, && \textit{meta}\text{-phosphoric acid;}\\
&P_2O_5 + 2H_2O = H_4P_2O_7 && \textit{pyro}\text{-phosphoric acid;}\\
&P_2O_5 + 3H_2O = H_6P_2O_8 = 2H_3PO_4, && \textit{ortho}\text{-phosphric acid.}
\end{aligned}$$

Hypophosphorous acid



$\left(H-O-P\begin{matrix} H \\ O-H \end{matrix} \right)$

— **preparation**:

Phosphorus boiled with a solution of sodium hydrate yields sodium hypophosphite and phosphuretted hydrogen:

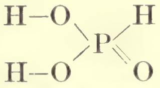
$$4P + 3NaOH + 3H_2O = 3H_2PO.ONa + PH_3.$$

The acid is obtained by heating this hypophosphite with sulphuric acid.

Hypophosphorous acid is a strong oxidizing agent. It forms salts called hypophosphites, several of which are used medicinally.

Although this acid has three hydrogen atoms (see graphic formula), only one is replaceable; therefore it is a monobasic acid.

Phosphorous acid



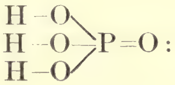
$\begin{matrix} H-O \\ H-O \end{matrix}>P\begin{matrix} H \\ =O \end{matrix}$

: It is obtained by adding phosphorous trichloride to water, the action produces phosphorous and hydrochloric acid:

$$PCl_3 + 3H_2O = H_3PO_3 + 3HCl.$$

It is a crystallizable solid, very deliquescent, rapidly absorbing oxygen and passing into phosphoric acid. Its salts are phosphites.

Orthophosphoric acid,



$\begin{matrix} H-O \\ H-O \\ H-O \end{matrix}>P=O$

: It may be *prepared* by several methods:

(1) By a solution of phosphorous pentoxide in water;
(2) By oxidizing phosphorus with nitric acid;
(3) By phosphorous pentachloride and water:

$$PCl_5 + 4H_2O = 5HCl + H_3PO_4.$$

Properties: It is a very powerful acid, but not poisonous. The aqueous solution evaporated and crystallized gives prismatic crystals. Heated to 160° C., the solution is unchanged; heated to 213° C., it gives up a molecule of water and forms pyrophosphoric acid; heated to a red heat, it gives up another molecule of water and forms metaphosphoric acid.

This orthophosphoric acid gives rise to all the natural phosphates. Other phosphates are artificially prepared.

Orthophosphates: Orthophosphoric acid forms salts called orthophosphates, and on account of being tribasic (having three replaceable hydrogens) it produces three kinds of salts.

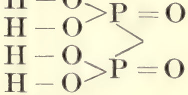
With *sodium* in combination these salts are:

NaH_2PO_4,	monosodium orthophosphate;
Na_2HPO_4,	disodium “
Na_3PO_4,	trisodium “

With *calcium:*

$CaH_4(PO_4)_2$,	monocalcium orthophosphate;
$Ca_2H_2(PO_4)_2$,	dicalcium “
$Ca_3(PO_4)_2$,	tricalcium “

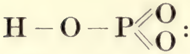
With *sodium* and *ammonium* a triple salt is produced, called sodium-ammonium hydrogen phosphate, $Na(NH_4)'HPO_4$. It is of great importance in blowpipe analyses, and is known as “salt of phosphorus” or “microcosmic salt.”

Pyrophosphoric acid, 

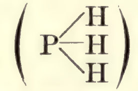
$$\begin{array}{l} \mathrm{H-O} \\ \mathrm{H-O} \\ \mathrm{H-O} \\ \mathrm{H-O} \end{array} \begin{array}{l} >\mathrm{P=O} \\ > \\ >\mathrm{P=O} \end{array}$$

: It is obtained by heating orthophosphoric acid.

Heat also produces pyro-*phosphates* from the ortho-*phosphates.*

Metaphosphoric acid,  $\mathrm{H-O-P}\begin{matrix} /\!\!/ \mathrm{O} \\ \backslash\!\!\backslash \mathrm{O} \end{matrix}$: It is prepared by heating orthophosphoric acid or pyrophosphoric acid to redness. It is extremely deliquescent, and requires to be kept in closely stoppered bottles. Heat separates a corresponding salt into ammonia, water, and sodium metaphosphate:

$$Na(NH_4)HPO_4 + \text{heat} = NH_3 + H_2O + NaPO_3.$$

Phosphoretted hydrogen  $\left(\mathrm{P}\begin{matrix} / \mathrm{H} \\ - \mathrm{H} \\ \backslash \mathrm{H} \end{matrix}\right)$ results from boiling water-slaked lime and phosphorus:

$$6H_2O + 3Ca(OH)_2 + 8P = 2PH_3 + 3CaH_4P_2O_4.$$

This gives phosphine and calcium hypophosphite. It is also prepared by the action of calcium phosphide and water.

It is a colorless gas, having an odor of decayed fish. As usually prepared it is inflammable, on account of the presence of vapors of P_2H_4. When perfectly pure it is not inflammable. It is slightly soluble in water.

ARSENIC. Symbol As. Atomic weight 75.

Occurrence: (*a*) *Free*, as mineral native arsenic.

(*b*) *Combined*, as sulphides, As_2S_2, mineral realgar;
As_2S_3, " orpiment.

Also as several arsenides, arsenates, and sulph-arsenides, the most important of which is arsenopyrite, FeAsS.

Preparation: In the laboratory its oxide, As_2O_3, is heated with charcoal in a closed crucible. The arsenic sublimes, and is collected as a brilliant steel-gray, seeming metallic mass.

In commerce several methods are employed:

(*a*) By heating the powdered mineral arsenopyrite in long earthen tubes, excluding air, the arsenic is volatilized and collected.

(*b*) By roasting the arsenates of cobalt, iron, and nickel, the arsenic passes off as a trioxide, As_2O_3, which may be purified and reduced by heating with charcoal in a retort.

Physical properties of arsenic: It is a steel-gray, metallic solid, crystalline and brittle. Its specific gravity is 5.7 to 5.9. Its molecule, like one of phosphorus, contains four atoms. Arsenic vapors have the odor of garlic. There is also a black, allotropic form, of specific gravity 4.7.

Chemical properties: It tarnishes in the air and volatilizes without fusion when heated. If air be present, it oxidizes to As_2O_3.

It combines with metals analogously to sulphur and phosphorus.

Uses of the compounds of arsenic: Sodium arsenite is used as a mordant in calico-printing.

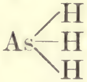
A double salt of copper arsenite and copper acetate is known as *Paris green*. This brilliant pigment is used to color wallpaper and to destroy insects. Enormous quantities are consumed in destroying the Colorado potato-beetle.

Arsenite of copper, *Scheele's green*, is used as a pigment. The trioxide, As_2O_3, is used in preparing aniline-red and in the manufacture of glass for lamp-shades and ornaments of a milky or opaque appearance.

Medicinally, various solutions are employed.

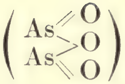
Compounds of Arsenic.

With hydrogen, AsH_3, arsenuretted hydrogen;
" oxygen, As_2O_3, arsenic trioxide;
" " As_2O_5, " pentoxide;
" sulphur, As_2S_2, As_2S_3, As_2S_5.

Arsenuretted hydrogen,  $As\begin{cases}H\\H\\H\end{cases}$: It is evolved by the action of zinc and sulphuric acid on any soluble compound of arsenic.

It is a poisonous, inflammable gas, readily condensing in a black, metallic deposit on cold porcelain or glass held in its flame. This fact constitutes the basis of Marsh's test for arsenic. It is an extremely delicate test, and is used in cases of arsenic-poisoning.

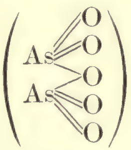
Stibine, SbH_3, gives a similar reaction and black deposit. Their recognition is by reagents.

Arsenious oxide or arsenic trioxide : It is prepared (1) by burning arsenic in the air; (2) by roasting arsenical minerals.

It is a heavy, white, glassy substance, with conchoidal fracture. It is soluble in water, forming arsenous acid:

$$As_2O_3 + 3H_2O = 2H_2AsO_3.$$

The oxides and acids have a sweet and astringent taste, and are intensely poisonous.

Arsenic pentoxide : It is produced by the action of hot hydrochloric acid on the trioxide and evaporating to dryness.

Properties: It is a white, anhydrous mass, uniting water to form arsenic acid:

$$As_2O_5 + 3H_2O = 2H_2AsO_4.$$

This is less poisonous than the arsenous compounds.

Arsenic disulphide: As_2S_2 is prepared by heating metallic arsenic with a *proper* proportion of sulphur. It is an orange-red, fusible, volatile solid.

Arsenic trisulphide: It may be obtained by heating sulphur and metallic arsenic in proper proportions or by precipitating it from arsenous acid by hydrogen disulphide, thus producing a golden-yellow, fusible, volatile solid.

The *pentoxide* is unimportant.

BORON. Symbol B. Atomic weight 11.

Occurrence: It is found in combination as boric acid, H_3BO_3, and as borax, $Na_2B_4O_7,10H_2O$.

Preparation: *Amorphous boron* is produced by heating sodium with boron trioxide. The amorphous form heated with aluminium gives a *crystalline variety*.

Properties: It is allotropic.

The amorphous powder is dark brown.

The crystalline variety is octahedral, specific gravity 2.68, infusible, and nearly as hard as the diamond. It is a triad.

Uses: (1) medicinally, it is used as an *antiseptic.*

(2) It is used in blowpipe analyses.

(3) Its main use is for the manufacture of borax.

Important compounds of boron:

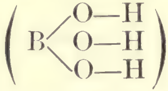
B_2O_3, boric oxide;
H_3BO_3, " acid;
$Na_2B_4O_7,10H_2O$, borax.

With hydrogen as BH_3, a gas resembling NH_3 and PH_3; with halogens as BF_3, a gas, and BCl_3, a volatile liquid; with nitrogen as BN, a brown nitride.

Boric oxide unites with water to form *boric acids* and with metallic oxides to form *borates.*

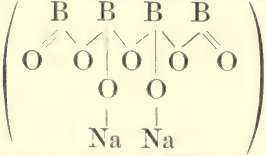
Acids of boron:

$B_2O_3 + H_2O = 2HBO_2$, *meta*-boric acid, non-important;
$2B_2O_3 + H_2O = H_2B_4O_7$, *pyro*-boric acid;
$B_2O_3 + 3H_2O = 2H_3BO_3$, *ortho*-boric acid.

Boric acid : It is a product of the springs of volcanic districts in Tuscany.

Preparation: (1) By concentrating natural spring waters; (2) By the action of sulphuric acid on borax.

Properties: It is antiseptic. In the fused state it dissolves metallic oxides to a limited extent, giving colored beads. It is soluble in water and imparts a green color to flame.

Borax : Pyroborate of sodium exists in the lagoon waters of Thibet and in Borax Lake, California.

Properties: It is feebly alkaline in its reaction, and when fused has the power of easily dissolving metallic oxides and imparting distinct colors to beads. This property makes it especially valuable as a blowpipe reagent. Mere traces of a metal will give strong colors. Iron gives yellow to brown; cobalt, blue; nickel, brown; copper, blue; manganese, amethyst; and chromium a green color.

SILICON. Symbol **Si.** Atomic weight 28.

Occurrence: It is always found in combination, and, next to oxygen, it is the most abundant element, occurring very extensively as SiO_2, quartz or sandstone, and in extensive groups of silicate minerals, such as clays, feld-spars, micas, amphibole, pyroxene, serpentine, and slates.

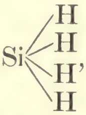
Preparation: It is obtained by heating the double fluoride of potassium and silicon ($2KF,SiF_4$) with the metal potassium.

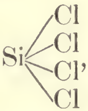
Properties: Silicon is allotropic, existing in three forms:

(1) A dark brown, lustreless powder;

(2) Needle-shaped crystals harder than glass, fusing at a red heat;

(3) Scaly crystals resembling graphite, but brighter colored and infusible.

Silicon hydride,  $\mathrm{Si}<\begin{matrix}\mathrm{H}\\ \mathrm{H}\\ \mathrm{H}\\ \mathrm{H}\end{matrix}$, **$SiH_4$,** silicon hydride or silica methane, is prepared by the action of hydrochloric acid on any magnesium compound containing silicon. It is a colorless gas, burning with a white flame.

Silicon tetrachloride,  $\mathrm{Si}<\begin{matrix}\mathrm{Cl}\\ \mathrm{Cl}\\ \mathrm{Cl}\\ \mathrm{Cl}\end{matrix}$, **$SiCl_4$,** is formed by the direct combination of its elements or by the action of dry chlorine gas on carbon and silicon oxide, SiO_2. It is a colorless, volatile liquid, which with water yields hydrochloric acid and gelatinous silica. A trichloride, Si_2Cl_6, is also formed.

Silica: Silica is silicon dioxide, SiO_2, constituting the mineral quartz. It is the only oxide of silicon, and either alone or in combination forms a large proportion of the earth's crust.

As prepared in the laboratory, it is a fine, white, tasteless powder, specific gravity of 2.66, fusible only in the oxyhydrogen blowpipe or electric furnace. As the crystallized mineral, quartz, it is transparent and generally clear. It is 7 in the scale of hardness.

CARBON. Symbol **C.** Atomic weight 12.

Occurrence: It occurs free, as the diamond and graphite (plumbago or black-lead).

Combined, it exists in animal and vegetable life (see Organic Chemistry), and in many kinds of carbonate minerals, the most important of which are:

Carbonate of iron (siderite)	Used as ores for the production of the metals.
“ “ copper (malachite)	
“ “ lead (cerussite)	
“ “ zinc (smithsonite)	
“ “ calcium (calcite)	Marbles, used for building and ornamental purposes.
“ “ “ and magnesium (dolomite)	
“ “ magnesium (magnesite)	(1) Heat-resisting material. (2) Used in the manufacture of Epsom salt, $MgSO_4 + 7H_2O$.

(See Organic Chemistry, for compounds of carbon and hydrogen.)

The coals, petroleum, and natural gas are compounds of carbon, hydrogen, and oxygen. Carbon and oxygen, CO_2, are found in the atmosphere.

Preparation: Carbon is prepared by the dry distillation of wood. Woody tissue is common cellulose, $C_{18}H_{30}O_{15}$, with minute quantities of coloring-matter and assimilated mineral matter, namely, salts of potassium and sodium, which remain as ash after the charcoal is burned. Wood subjected to heat and protected from the air yields charcoal, which is practically pure carbon.

Gas-carbon is formed as a coating in gas-retorts, and is used in the Bunsen galvanic batteries; also for making carbon points for the arc light.

Properties: Carbon, being allotropic, presents special properties for each form.

The **diamond** occurs native in India, South Africa, Borneo, Brazil, and to some extent in the United States. In 1880 Mr. J. B. Hanney, of Glasgow, produced some small diamonds artificially. They were not a commercial success. All diamonds are distinctly crystalline, and owe their brilliancy to their power to refract light. They vary from white to many tints in color. The diamond is the hardest substance known, and is cut and polished with its own powder. When subjected to heat, in the absence of air, it is infusible; but in the oxyhydrogen blowpipe it can be burned into carbon dioxide. It is a bad conductor of electricity. Its specific gravity is 3.48+.

The diamond is used for ornamentation, jewels; for cutting glass; for tipping rock-boring machines, etc., the less valuable kinds being employed for the latter purposes.

Graphite occurs in mines of Siberia, Ceylon, England, California, Vermont, and Ticonderoga, N. Y. It is frequently a product in the manufacture of pig or cast-iron, having been dissolved by the iron and crystallized by cooling, and called "kish." It is black, soft, unctuous, and crystallizes in six-sided plates, of specific gravity 2.25 to 2.27. In solubility and fusibility it resembles the diamond, but it is a good conductor of electricity.

Lead-pencils and stove-polish are made of graphite. This form of carbon is used as a lubricant for machinery, as a paint for metallic material, in electrotyping, as a glazing for grains of gunpowder; also as a mould-wash in iron foundries, a wash for iron railings, and, when mixed with clay and sand as a material for crucibles.

Amorphous carbon: *Charcoal* is the result of imperfect combustion of wood. It is black and very porous, the latter property making it an excellent absorbent of gases. One c.c. of charcoal properly made will absorb about 18 c.c. of oxygen, 68 c.c. of carbon dioxide, or 172 c.c. of ammonia; hence it may be used as a disinfectant and to absorb noxious gases. It is also a decolorizer.

Made from bones instead of wood, it is called *bone-black* or *animal charcoal*, a substance extensively used in sugar refineries for decolorizing sugar. Carbonized blood (blood burned with insufficient air) is used for the same purpose.

The collected smoke (carbon) of burning tar, rosin, turpentine, petroleum, etc., becomes the lampblack of commerce, and is used to make printers' ink, India ink, and black paint.

Wood-charcoal is used in metallurgy, as fuel, and in the manufacture of *crucibles and cementation steel.*

A description of the carbon compounds is given in Organic Chemistry, a few, however, are here described:

Carbon monoxide, CO, commonly called carbonic oxide, is produced when carbon dioxide is passed over incandescent carbon or red-hot metallic iron. One-half of the oxygen of CO_2 is removed and the oxygen is set free, combining with carbon of iron:

$$CO_2 + C = 2CO \text{ or } 3CO_2 + 2Fe = Fe_2O_3 + 3CO.$$

Crystallized oxalic acid decomposed by sulphuric acid produces water, carbon monoxide, and carbon dioxide. These gases are separated by passing them through caustic potash, KOH, which absorbs the dioxide, leaving the monoxide:

$$H_2C_2O_4 = H_2O + CO_2 + CO.$$

Properties: Carbon monoxide is a combustible gas, burning with a pale blue flame, as seen in coal-fires, and producing CO_2. It is colorless, odorless, and extremely poisonous.

Use: It is one of the chief constituents of water-gas. It is also produced in *blast furnaces for iron*, being a principal factor in the reduction of iron from its ores.

Carbon dioxide, CO_2, or carbonic anhydride, commonly called carbonic acid gas, *occurs free* in the atmosphere; *dissolved* in the waters of mineral springs; in "*choke-damp*" of coal mines, and in *mineral carbonates.*

Preparation: (1) By burning carbon with an excess of oxygen;

(2) By decomposing carbonates;

(3) By respiration and fermentation;

(4) By sulphuric or hydrochloric acid and limestone:

$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2.$$

Properties: CO_2 has a pungent taste and odor and does not support life or combustion. When liquefied by cold and pressure, and a portion of this liquid is allowed to evaporate or escape by a jet, sufficient heat is absorbed to freeze or solidify the portion remaining. In this form it is a white, crystalline, snow-like solid, of a temperature of —78° C.

This gas is soluble in water and other liquids, as exemplified by soda-water, effervescent wines, ales, beer, etc. It is also an important factor in cooking. The fermentation of yeast, the action of baking-powders, and the use of sour milk and a carbonate evolve CO_2 and render bread and cakes light and porous.

Test: It renders calcium hydrate or lime-water turbid, forming calcium carbonate and water:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

With water, this gas forms carbonic acid, H_2CO_3.

Free cyanogen ($N \equiv C — C \equiv N$): Carbon and nitrogen do not unite directly; but by passing air over potassium carbonate and charcoal, potassium cyanide ($K — CN$) is obtained; and from it free cyanogen may be prepared. The latter is a colorless gas, with an odor suggesting peach-kernels, burning with a beautiful purple flame. The radical $N \equiv C —$ (cyanogen) forms compounds.

Compounds of cyanogen: Cyanogen combines indirectly with hydrogen, forming hydrocyanic acid, $H — CN$, better known as prussic acid, a colorless, mobile liquid of peculiar odor. It forms salts with bases. It is extremely poisonous in its character.

Other compounds are important as *reagents*—viz.:

Potassium cyanide, KCN; Potassium ferrocyanide, $K_4Fe(CN)_6$; Potassium ferricyanide, $K_6Fe(CN)_{12}$.

"Cy" is often substituted for "CN"; as K_4FeCy_6, etc. Both it and its salts are very powerful poisons.

Carbon disulphide $\left(C{\overset{S}{\underset{S}{<}}} \right)$: Carbon di- or bisulphide is

produced by passing the vapors of sulphur over red-hot coals. It is a colorless liquid, of great refractive power, and as commercially prepared it has a nauseous odor, due to impurities. In a pure state its odor suggests ether.

When a mixture of carbon disulphide vapors and oxygen is ignited, a violent explosion ensues:

$$CS_2 + 3O_2 = CO_2 + 2SO_2.$$

Its specific gravity is 1.29, and it boils at 46° C.

It is a solvent for sulphur, phosphorus, rubber, fats, and oils, and is used also to extract fats from animal matter, as well as to facilitate some of the processes in the manufacture of rubber goods.

THE METALS OR METALLIC ELEMENTS.

Of the *seventy* elements now known, about *fifty* are **metals,** some of which, however, occur in very small quantities. The line of demarcation between metals and non-metals is not strictly drawn. Their chief differences are of a chemical nature. In general, the oxides of non-metals unite with water to form acids, while those of the metals similarly produce bases. The only acid-forming metallic oxides are those which contain an unusually large proportion of oxygen. Excepting mercury, all metals are solid at ordinary temperatures, and are good conductors of heat and electricity. Many of them are capable of being highly polished and of reflecting light, the latter property giving the so-called metallic lustre. Exclusive of films, like gold-leaf, which will transmit light, all are opaque and usually dense, heavy, ductile, tenacious, and malleable (bismuth and antimony are brittle). They are invariably electro-positive, and in color usually gray or whitish. Calcium, strontium, and gold are yellow; copper a dull red. In hardness there are various grades from liquid mercury to iridium, which will scratch the hardest steel. Their fusibility and specific gravities widely differ, as appears by the following tables:

SPECIFIC GRAVITIES OF SOME METALS.

(F. W. CLARKE.)

NAME.	SP. GR.	NAME.	SP. GR.
Aluminium	2.583	Manganese	8.013
Antimony	6.700	Mercury	13.597
Arsenic	5.727	Molybdenum	8.600
Barium	3.750	Nickel	8.900
Bismuth	9.823	Osmium	22.477
Cadmium	8.670	Palladium	12.000
Caesium	1.885	Platinum	21.504
Calcium	1.584	Potassium	0.875
Cerium	6.728	Rhodium	12.100
Chromium	7.300	Rubidium	1.520
Cobalt	8.957	Ruthenium	12.261
Columbium	7.060	Silver	10.512
Copper	8.945	Sodium	0.974
Didymium	6.544	Strontium	2.580
Gallium	5.940	Tantalum	10.780
Glucinum	1.640	Tellurium	6.250
Gold	19.298	Thallium	11.910
Indium	7.421	Thorium	11.230
Iridium	22.421	Tin	7.300
Iron	7.800	Tungsten	19.261
Lanthanum	6.163	Uranium	18.685
Lead	11.335	Vanadium	5.500
Lithium	0.585	Zinc	7.180
Magnesium	1.75	Zirconium	4.15

		Melting-point.
Fusible below a red heat.	Mercury	—39.44° C.
	Gallium	+30.
	Rubidium	38.5
	Potassium	62.5
	Sodium	95.6
	Lithium	180.
	Tin	235.
	Bismuth	270.
	Thallium	294.
	Cadmium	315.
	Lead	334.
	Zinc	423.
	Antimony	425.
	Aluminium	625.

		Melting-point.
Infusible below a red heat.	Silver	1000.
	Copper	1090.
	Gold	1102.
	Cast-iron	1530.
	Pure iron	High forge heat.
	Nickel	
	Cobalt	
	Palladium	1500.
	Molybdenum	Agglomerate, but do not melt in forge.
	Uranium	
	Tungsten	
	Chromium	
	Titanium	Infusible in ordinary blast furnaces. Fusible by oxyhydrogen blowpipe.
	Cerium	
	Osmium	
	Iridium	
	Rhodium	
	Platinum*	
	Tantalum	

Some metals assume a pasty state intermediate between solid and liquid, a property especially valuable in iron and platinum.

Classification of metals: (1) *Metals of the alkalies:* Potassium, sodium, lithium, rubidium, caesium.

(2) *Alkaline earths:* Calcium, strontium, and barium.

(3) *Magnesium group:* Beryllum, magnesium, zinc, and cadmium.

(4) *Lead group:* Lead, thallium.

(5) *Copper group:* Copper, silver, mercury.

(6) *Yttrium group:* Yttrium, erbium, terbium, ytterbium, scandium, decipium, lanthanum, cerium, didymium, and samarium.

(7) *Aluminium group:* Aluminium, indium, gallium.

(8) *Iron group:* Manganese, iron, cobalt, nickel.

(9) *Chromium group:* Chromium, molybdenum, tungsten, uranium.

(10) *Tin group:* Tin, titanium, zirconium, thorium.

(11) *Antimony group:* Vanadium, antimony, bismuth, tantalum, niobium.

(12) *Platinum group:* Gold, platinum, palladium, rhodium, iridium, ruthenium, osmium.

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*Platinum melts at 1775° C.

METALS OF THE ALKALIES.

Potassium, sodium, caesium, rubidium, and lithium: They are soft, easily fusible, and volatile at high temperatures. They combine very energetically with oxygen, decompose water at all temperatures, and form strongly basic oxides which are very soluble in water, yielding powerfully caustic and alkaline hydroxides not decomposable by heat. Their carbonates are soluble in water, and each metal forms only one chloride. The hypothetical metal ammonium is usually added to the list of alkali metals, on account of the general similarity of its compounds to those of potassium and sodium.

POTASSIUM. Symbol K. Atomic weight 39.

History, occurrence, and preparation: It was discovered by Sir Humphrey Davy in 1807.

Potassium is one of the constituents of granitic minerals, of clay soils, and of sea-water.

It is prepared by heating to a high temperature potassium monoxide and charcoal in an open retort:

$$K_2O + C = CO + K_2.$$

The potassium distils, and is collected under petroleum, then purified by redistillation. It may also be prepared by decomposing potassium hydrate, KOH, by an electric current.

Physical and chemical properties: It is a lustrous, silver-white metal, soft at the temperature of the air, plastic, and easily cut with a knife. At 0° C. it is brittle and crystalline.

Exposed to the air, it rapidly tarnishes on account of the formation of a thin film of oxide; thrown on water it instantly takes fire, liberating hydrogen and burning with a purple flame. It combines with non-metals, such as chlorine and sulphur, evolving heat and light. As a reducing agent it is valuable in the laboratory.

Potassium chloride, KCl: It is found in sea-water and at the Stassfurt deposits in Germany. It reduces to cubic crystals, which are soluble in water, and is obtained by heating potassium chlorate:

$$2KClO_3 + \text{heat} = 2KCl + 3O_2.$$

It is used to prepare other potassium salts, and in an impure state it is employed as a constituent of fertilizers.

Potassium iodide, KI, occurs in sea-water, and is taken up by sea-weeds. It may be prepared by adding iodine to caustic potash—

$$6KOH + 6I = 5KI + 3H_2O + KIO_3,$$

or by reducing iodate of potassium. It exists as white cubic crystals, soluble in water. It is used *medicinally.*

Potassium bromide, KBr, is prepared by adding bromine to caustic potash. It is found in sea-water and in mineral springs.

It is used in the manufacture of the aniline color eosene, and as a medicine.

Potassium monoxide, K_2O, is formed by exposing thin slices of metallic potassium to dry air. It is white, deliquescent, and caustic, combining energetically with water to produce potassium hydrate (potassa).

Caustic potash, or **potassium hydrate, KOH,** is produced by decomposing potassium carbonate with calcium hydroxide (slaked lime):

$$K_2CO_3 + CaH_2O_2 = CaCO_3 + 2KHO.$$

Calcium carbonate is precipitated as a powder, and the solution of potassium hydroxide evaporated to dryness and cast into sticks.

Properties: It is a white solid, very deliquescent, soluble in water and alcohol. Its solution is intensely alkaline, neutralizing the strongest acids and dissolving the skin and other organic matters.

Its chief uses are in the *manufacture of soap* and as a *caustic.*

Potassium chlorate, $KClO_3$: The *preparation* is simply passing chlorine gas through potassium hydrate; or by the action of chloride of potassium on chlorate of calcium:

$$6KOH + 6Cl = 5KCl + KClO_3 + 3H_2O;$$
$$Ca(ClO_3)_2 + 2KCl = 2KClO_3 + CaCl_2.$$

The crystals thus obtained are white and anhydrous, with a taste resembling nitre. They deflagrate violently with combustible matter, and explode by friction or blows.

Medicinally, it is used for allaying *inflammation of the* *throat;* in the arts, it is employed in making matches, in calico-printing, and as a source of oxygen.

Potassium sulphate, K_2SO_4, occurs in the ashes of land and sea plants and in Stassfurt deposits. The residue from nitric acid manufactories is its chief commercial source :

$$2KNO_3 + H_2SO_4 = 2HNO_3 + K_2SO_4.$$

It is a white, crystalline substance, soluble in water.

Potassium nitrate, KNO_3, often called nitre or saltpetre, is found native in various localities, particularly in India, as an efflorescence of the soil.

It is *prepared* (1) by subjecting animal matter containing nitrogen, wood-ashes, and lime to the action of the air. The nitric acid thus produced unites with the lime and potash to form nitrates. After boiling with water, potassium carbonate is added to decompose the nitrate of lime. The potassium nitrate crystallizes out from the liquid.

(2) By decomposing native sodium nitrate, $NaNO_3$, with K_2CO_3, and potassium chloride, KCl. In Belgium, the refuse K_2CO_3 from the beet-root sugar manufactory is largely employed for this purpose.

It crystallizes in six-sided prisms, is soluble in water, and is saline and cooling to the taste. When thrown on molten metals rapid oxidation ensues, due to the liberation of oxygen. It is thus used to purify molten gold and silver. It is extensively used in the manufacture of gunpowder and in pyrotechnics.

Gunpowder is manufactured from charcoal, sulphur, and potassium nitrate. Its explosion produces two expansible gases and smoke of potassium sulphide :

$$3C + 2KNO_3 + S = 3CO_2 + K_2S + 2N.$$

Potassium carbonate, K_2CO_3, commercially termed "pearl-ash," is prepared by evaporating the lye from ashes of plants. It is also obtained from beet-sugar factories, from the Stassfurt deposits, and from the washings of wool.

Potassium bicarbonate, $KHCO_3$, is prepared by passing carbon dioxide through a cold solution of potassium carbonate; the bicarbonate is formed.

Potassium sulphides: They are the mono, bi, tri, tetra, and pentasulphide, or K_2S_2, K_2S_3, K_2S_4, K_2S_5, and KHS, or the hydrosulphide.

SODIUM. Symbol Na. Atomic weight 12.

Sodium is a silver-white metal, soft at common temperature, readily tarnishing in the air and decomposing water, and igniting the liberated hydrogen if the water be warm. *Its flame is yellow.*

Sodium chloride, NaCl, or *common salt*, occurs in many parts of the world in solid beds or irregular strata, as in England, Spain, Germany, United States, and other countries. An inexhaustible supply exists also in the waters of the oceans, and large quantities are obtained from mineral springs.

It is *prepared* by the evaporation of natural brines and purified by crystallizing.

Properties: It crystallizes in cubes, which are often arranged in pyramidal steps, called "*hopper-shaped*."

It melts at a red heat, volatilizes at high temperatures, and is soluble in about 2½ parts of water. Its solubility is not appreciably increased by heat. It is nearly insoluble in alcohol. It is used as a condiment and food preservative; also in the manufacture of chlorine and hydrochloric acid; as a fertilizer; in glazing earthenware, and as a flux.

Sodium oxides: *Oxide of sodium*, Na_2O, is similar to the corresponding potassium compound. The *dioxide*, Na_2O_2, is formed by oxidizing metallic sodium at 200° C. in a current of dry air.

Sodium hydroxide, NaOH, is prepared by decomposing a solution of sodium carbonate, Na_2CO_3, with calcium hydroxide, $Ca_2O_2H_2$, in a manner similar to the preparation of potassium hydroxide. It is a white, fusible, deliquescent solid, soluble in water, a powerful alkali, caustic, and a solvent of animal matter. It is used extensively in the manufacture of soap.

Sodium hypochlorite, NaOCl (*eau de Labarraque*), is contained together with the chloride in the bleaching solution. It is prepared by passing chlorine into NaHO.

Sodium chlorate, $NaClO_3$, is produced from sodium carbonate and chloric acid. It is used in calico-printing and in the manufacture of aniline-black.

Sodium sulphate, $Na_2SO_4,10H_2O_4$, is a product of many chemical operations. It is crystalline and efflorescent, possessing a bitter taste. Medicinally it is used as a purgative, and is known as *Glauber's salt.*

Sodium thiosulphate, $Na_2S_2O_3$, formerly called *hyposulphite,* is prepared from Na_2SO_3 by the addition of sulphur. It is used in *photography* to dissolve unaltered silver chloride; in *paper manufacture* as "anti-chlor," and in *lixiviating* silver ores.

Sodium nitrate, $NaNO_3$, *cubic nitre,* or *Chile saltpetre,* occurs native in enormous quantity in parts of South America (Chile). It is deliquescent, very soluble in water, and is used:

(1) In the manufacture of nitric acid;
(2) In the preparation of potassium nitrate;
(3) As a top dresser in fertilizing.

It cannot be used for gunpowder, as the mixture burns too slowly and becomes damp in the air.

The **phosphates of sodium** are:

Hydro-di-sodic-phosphate,	$Na_2HPO_4,12H_2O$;
Tri-sodic-orthophosphate,	$Na_3PO_4,12H_2O$;
Mono-sodic-orthophosphate,	NaH_2PO_4,H_2O ;
Normal pyrophosphate,	$Na_4P_2O_7,10H_2O$;
Acid pyrophosphate,	$Na_2H_2P_2O_7$;
Metaphosphates,	$nNaPO_3$.

$n = 1, 2, 3$, etc., called mono, di, tri, etc.

The **arsenates of sodium** resemble the phosphates. An impure sodium arsenate is largely used in calico-printing and in clearing cloth after mordanting.

Silicates of sodium: Metasilicate, Na_2SiO_3 or Na_2O,SiO_2; quadrisilicate, $Na_2Si_4O_9$ or $Na_2O,4SiO_2$.

Both are prepared by fusing together Na_2CO_3 and SiO_2 in proper amounts.

The **quadrisilicate, $Na_2Si_4O_9$,** is known as *soluble glass,* as it dissolves in water. It has extensive uses, as follows:

(1) In the manufacture of artificial stone;
(2) In cement;

(3) In the manufacture of silicate soap.
(4) In surgery to impregnate bandages.

Sodium carbonate—preparation: $Na_2CO_3,10H_2O$, normal sodium carbonate, was formerly prepared from ashes of seaweeds and of plants which grow by the sea-side. It is now manufactured on a large scale from common salt. The most important processes are Leblanc's and the ammonia-soda process.

The former process consists, first, in the decomposition of NaCl by H_2SO_4, yielding HCl and Na_2SO_4, called "*salt-cake*"*;* then in mixing the salt-cake with chalk and coal, and heating to fusion in a reverberatory furnace. The crude product is called "*black-ash*" or "*ball soda.*" This is purified, and is the *soda-ash* of commerce, and contains from 48 to 52 per cent. of Na_2O. This commercial product can be further purified by solution and crystallization.

The *ammonia-soda process* consists in decomposing a solution of NaCl with ammonium carbonate, whereby the greater part of the sodium is precipitated as bicarbonate, while the ammonia remains in solution as ammonium chloride. This latter salt is heated with lime to liberate ammonia, which is then reconverted into bicarbonate by the carbonic acid evolved in the conversion of the sodium bicarbonate into monocarbonate by heat; and the ammonium bicarbonate thus reproduced is employed to decompose fresh portions of sodium chloride, so that the process is made continuous.

Properties: The ordinary monoclinic crystals contain 10 molecules of water of crystallization, but it may be made to crystallize with varying amounts. It is efflorescent in dry air, very soluble in water, has a strong, disagreeable alkaline taste, and a powerful alkaline reaction.

Bicarbonate of sodium, or acid carbonate of sodium, $NaHCO_3$, is prepared by passing CO_2 gas into a cold solution of Na_2CO_3. It is a crystalline, white powder, soluble in 10 to 15 parts of water, and feebly alkaline. It is used in baking-powder.

Tests for sodium compounds: (1) They tinge flame *yellow*.

(2) Antimonate of potassium throws down a *white* precipitate of sodium antimonate, providing the solution has been previously freed from all bases except the alkalies.

(3) All the salts, except the antimonate, are soluble in water.
(4) Their spectrum shows a bright line in the yellow band.

LITHIUM (*lithos*, a stone). Symbol **Li.** Atomic weight 7.

Occurrence, preparation, and tests: Lithium occurs in the minerals lepidolite and petalite, and in small quantities in mineral springs.

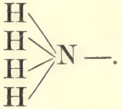
It is obtained by decomposing the fused chloride by electrolysis. Like sodium, it is a white metal, easily oxidized. It is the lightest solid known. Lithia or lithium hydrate, LiOH, is much less soluble than potassium or sodium hydrate. It forms salts with carbonic, hydrochloric, sulphuric, and phosphoric acids.

The salts of lithium color the outer flame of the blowpipe carmine-red, and the spectrum presents one bright red line, by means of which the minutest trace of lithium may be detected.

CAESIUM and RUBIDIUM. Atomic weights 133 and 85.4. Symbols **Cs** and **Rb.**

Both are widely diffused in nature, but in very small amounts in minerals and mineral waters. The mineral lepidolite has been found to contain as much as 0.2 per cent. of rubidium. These rare elements form many salts. The hydroxides are powerful bases. Like potassium, they are soft at ordinary temperatures and easily oxidized. They take fire when thrown on water.

AMMONIUM,



$$\left.\begin{matrix}H\\H\\H\\H\end{matrix}\right\rangle N-.$$

Ammonium is a compound monovalent radical. Its salts are most conveniently studied in this place on account of their close analogy to K and Na. These salts are formed by the direct union of ammonia, NH_3, with acids; as:

$$\begin{aligned}NH_3 + HCl &= NH_4Cl;\\ NH_3 + HNO_3 &= NH_4(NO_3);\\ 2NH_3 + H_2SO_4 &= (NH_4)_2SO_4.\end{aligned}$$

Ammonium chloride, NH_4Cl, or sal-ammoniac, is prepared from the ammoniacal liquor of gas-works and from condensed products in the manufacture of bone-black. It forms anhydrous crystals having a sharp, saline taste, is soluble in cold water, and sublimes without decomposition.

Ammonium sulphate, $(NH_4)_2SO_4$, is prepared by adding H_2SO_4 in excess to the coal-gas liquor just mentioned and purifying the product. The crystals are white and very soluble in water. It is much employed as a fertilizer and for the manufacture of alum.

Ammonium nitrate, NH_4NO_3, is obtained by adding nitric acid to ammonium carbonate and crystallizing the product. The crystals are white, six-sided prisms, slightly deliquescent, soluble in 2 parts of cold water, producing considerable depression of temperature; when heated above 230° C. they are decomposed into water and nitrous oxide gas:

$$NH_4NO_3 + \text{heat} = 2H_2O + N_2O.$$

Phosphates of ammonium: Normal or triammonic salts, $(NH_4)_3PO_4$; sodium ammonium hydrogen phosphate (*phosphorous salt; microcosmic salt*), $NaNH_4HPO_4,4H_2O$. The latter is valuable as a flux in blowpipe experiments.

Normal ammonium carbonate, $(NH_4)_2CO_3$, is obtained by subliming chloride of ammonium and calcium carbonate:

$$2NH_4Cl + CaCo_3 = (NH_4)_2CO_3 + CaCl_2.$$

It is an unstable compound, decomposing in contact with air, with the evolution of ammonia.

Acid ammonium carbonate, or bicarbonate of ammonium, NH_4HCO_3, is found in deposits of guano on the west coast of Patagonia. It forms large triclinic crystals, volatilizes slowly when exposed to the air, and is soluble in 8 parts of water.

Caustic potash, KHO, a solution of mercuric iodide, HgI_2, and of potassium iodide, KI, together, give to any ammoniacal solution a brown coloration or precipitate of di-mercur-ammonium iodide, NHg_2I:

$$NH_3 + 2HgI_2 + 4KI + 3KHO = 2H_2O + 7KI + NHg_2I + H_2O.$$

Ammonium hydrogen sulphide, NH_4HS, is prepared by saturating a solution of ammonia with sulphuretted hydrogen gas. It is a yellow liquid with an offensive odor.

It has great practical utility in chemical analysis, as it yields with most metallic solutions precipitates which are often characteristic.

Tests for ammonium compounds: (1) All the salts are white and volatilized by heat. If heated with caustic potash, soda, or lime, they yield ammonia gas, known by its pungent odor and its alkaline reaction on litmus-paper.

(2) Perchloride of platinum gives a yellow precipitate of ammonio-platino-chloride, NH_4PtCl_5.

(3) Nitrate of silver and a solution of arsenous acid with ammonium hydrate, NH_4HO, give a yellow precipitate.

METALS OF THE ALKALINE EARTHS.

The **metals of the alkaline earths,** *calcium, strontium,* and *barium,* form oxides less soluble in water than the true alkalies. They exhibit a similar taste, causticity, and action on vegetable colors; their carbonates are insoluble in water; the sulphates of calcium and strontium are slightly soluble; the sulphate of barium is insoluble.

CALCIUM (*calx lime*). Symbol Ca. Atomic weight 39.9.

Occurrence: It is an abundant and widely diffused element, occurring as a carbonate in limestone, marble, chalk, coral, marl, etc. Its sulphate is gypsum; its fluoride, fluorite; its phosphate, apatite, and its silicates are many minerals.

The phosphate is an important ingredient of plants and bones.

Preparation and properties: (1) By electrolysis from calcium chloride;

(2) By heating calcium iodide with metallic sodium.

It is light yellow in color, hard as gold, very ductile and malleable. It tarnishes slowly in air, decomposes water, burns with a bright light when heated in air, brilliantly when heated in oxygen or vapor of bromine, iodine, or sulphur, and has a specific gravity of 1.5778.

Calcium chloride, $CaCl_2$, is prepared by the action of hydrochloric acid on calcium carbonate:

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2.$$

Properties and uses: Its colorless, prismatic, strongly deliquescent crystals contain six molecules of water of crystallization, $CaCl_2,6H_2O$. When the water is driven off by heat the anhydrous chloride is in a porous state and absorbs water with great avidity. It is of great use in desiccating gases.

When $CaCl_2,6H_2O$ is mixed with powdered ice or snow it produces a powerful freezing-mixture.

Calcium bromide, $CaBr_2$, and **calcium iodide, CaI_2,** closely resemble the chloride.

Calcium fluoride, CaF_2, *fluorspar*, occurs in the mineral fluorite, beautifully crystallized and often highly colored. Some varieties phosphoresce when heated. It is the most abundant source of hydrofluoric acid and is of great value in etching glass.

Calcium monoxide, CaO, lime, quicklime, is prepared by heating the carbonate:

$$CaCO_3 = CaO + CO_2.$$

It is produced in great quantities in lime-kilns.

Properties: It is white, caustic, infusible, giving an intense white light in the oxyhydrogen flame (Drummond or calcium light).

It is phosphorescent at a high temperature and unites violently with water, evolving great heat, sufficient sometimes to ignite buildings. Its union with water yields the hydroxide:

$$CaH_2O_2 \text{ or } CaO_3H_2O.$$

Calcium dioxide, CaO_2, is prepared by the action of hydrogen dioxide on lime-water, thus producing microscopic crystals:

$$CaO_2,8H_2O.$$

Calcium hydroxide, CaH_2O_2 or **$Ca(OH)_2$,** caustic lime, or slaked lime, is prepared by the action of water on calcium monoxide.

Alkaline in reaction, it neutralizes acids, attacks organic matter vigorously, and is soluble in 730 parts of cold, but 1300 parts of warm water, forming *lime-water*.

Use: Its use is very extensive in the preparation of mortars* and cements; in tanneries, to remove hair from skins; as a fertilizer, as it decomposes organic matter in the soil and reacts on silicate of potassium, liberating potash for the use of plants; as a purifier for illuminating-gas; in the manufacture of bleaching-powder and caustic alkalies; as milk of lime, suspended in water, for whitewash; as lime-water to test for carbon dioxide.

Hydraulic cement: *Hydraulic cement* is prepared by heating lime containing clay and silica. Moisture converts them into silicates of lime and aluminium, which *set* and become impervious to water.

Chloride of lime, $CaOCl_2$ (bleaching-powder), is prepared by passing chlorine gas over moist calcium hydroxide.

When fresh it is a soft, white powder absorbing moisture from the air. It has a peculiar odor, is soluble in 10 parts of water, is decomposed by the action of carbonic acid in the air, and is the best commercial bleaching-powder. It contains about 30 per cent. of available chlorine. It is used extensively in dilute solutions as a *bleaching-agent*, the chlorine being set free by dilute acids:

$$\begin{aligned} CaOCl_2 + H_2SO_4 &= CaSO_4 + HClO + HCl; \\ HClO + HCl &= H_2O + Cl_2. \end{aligned}$$

It is also used as a disinfectant. By exposing the chloride in shallow vessels chlorine is slowly disengaged and mixed with the atmosphere, which it purifies by attacking the hydrogen of the offensive compounds, thus reorganizing their constituents into harmless products.

Calcium sulphate, $CaSO_4$, occurs native in the anhydrous form and as gypsum (selenite) with two molecules of water,

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*Mortar is made by mixing lime with water and sand; for interior plastering hair is added to bind the mass together. When first mixed, mortar is soft and pasty. It hardens as it dries, and by the absorption of carbon dioxide from the air becomes in time almost as hard as stone. In very old brickwork the mortar is often harder than the bricks themselves, due to the formation of the silicate of calcium.

$CaSO_4,2H_2O$. It is often associated with rock-salt. It is prepared by the action of sulphuric acid on calcium carbonate:

$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2.$$

Properties: It is soluble in about 500 parts of water, and often occurs with the carbonate in natural waters. Such waters are known as "hard" waters, and are objectionable for use in steam-boilers, as the lime salts form a crust known as "boiler-scale," which, being a non-conductor of heat, causes great waste of fuel. Hard waters are also objectionable for laundry purposes, the lime salts combining with the soaps to form insoluble lime soaps, and no lather can be produced until all the lime salts have been precipitated. This hardness is termed "*permanent hardness*," as boiling will not remove it.

Uses: The mineral gypsum when in white, translucent masses (alabaster) is used as an *ornamental stone*.

If gypsum is calcined, the anhydrous sulphate is produced, forming "*plaster-of-Paris*," which, when mixed with water, reabsorbs the two molecules of water and "sets" to a compact, solid mass. In solidifying it expands, and thus is of great value in making casts. It is used to some extent in *fertilizers*, as a "filler," and largely for hard finish to the surface of plastered walls; also in bandages for fractured bones.

Calcium nitrate, $Ca(NO_3)_2$, is prepared by the action of nitric acid on chalk. When heated and exposed to sunshine it appears luminous in the dark, and is called "*Baldwin's phosphorus*."

This nitrate is often found as an efflorescence on walls of stables through which urine and other organic substances have percolated.

Mono-calcic orthophosphate, $CaHPO_4$, occurs in urinary concretions as stellate groups of microscopic crystals.

The **tri-calcic orthophosphate, $Ca_3(PO_4)_2$**, occurs in a few minerals and is the chief mineral constituent of bones. It is prepared by the action of di-sodic orthophosphate, Na_2HPO_4, in an ammoniacal solution of calcium chloride, or from bone-ash and hydrochloric acid. It is a white powder, nearly insoluble in water.

Superphosphate of lime is a name applied to a mixture of mono-calcic orthophosphate, $CaHPO_4$, and calcium sulphate. It is prepared on a large scale by treating bone-ash, or phosphate minerals, with two-thirds their weight of sulphuric acid, and is used to a very great extent as a fertilizer.

Hypophosphite of calcium, $Ca(PO_2H_2)_2$, is prepared from phosphorus and milk of lime. It occurs as four-sided prisms, insoluble in alcohol, and is used *medicinally*.

Calcium carbonate, $CaCO_3$ (chalk, limestone, marble, etc.), occurs in almost every part of the world and is more or less contaminated with iron oxide, clay, and organic matter. In a pure state it forms beautiful transparent crystals. One variety, known as Iceland spar, possesses double refractive power, and is much used in instruments applied to studying polarized light (Nicol's prisms).

It is *prepared* by the addition of an alkaline carbonate to any solution of calcium.

Properties: It is almost insoluble in pure water, but freely soluble in water containing carbonic acid. The hardness of water due to the presence of $CaCO_3$ is called "*temporary hardness*," as this lime salt can be *removed:*

(1) Partially by boiling, producing precipitations, the CO_2 in water being driven off;

(2) By the addition of lime-water, the CO_2 is taken up and the carbonates are thus precipitated;

(3) By addition of ammonium chloride:

$$2NH_4Cl + CaCO_3 = CaCl_2 + (NH_4)_2CO_3.$$

The solubility of $CaCO_3$ in water containing CO_2, and its subsequent precipitation when the CO_2 is driven off, are the cause of the beautiful stalactites and stalagmites in the great limestone caverns, as in the Mammoth Cave, Ky.

Crystallized calcium carbonate is dimorphous, crystallizing in the hexagonal system as the mineral calcite, and in the orthorhombic system as the mineral aragonite. From any of the numerous crystals of calcite the cleavage-form, consisting of a rhombohedron of 105° 5′, can be obtained. The specific gravity of $CaCO_3$, as calcite, is 2.5–2.8; a saragonite is 2.9–3.28.

Prepared chalk is washed chalk wrought into lumps and dried.

Whiting is the same material, powdered.

The **sulphides of calcium** are:

Monosulphide, CaS; Bisulphide, CaS_2;
Pentasulphide, CaS_5.

Calcium phosphide results when vapor of phosphorus and fragments of lime are heated to redness in a porcelain crucible. It is a chocolate-brown compound, which, when thrown on water, spontaneously produces inflammable hydrogen phosphide.

The tests for calcium: (1) The spectrum yields a number of bright lines, of which a green line and an orange line on each side of the sodium line are the most characteristic.

(2) The chloride imparts a red coloration to the blowpipe-flame.

(3) Ammonium oxalate yields a precipitate of oxalate of calcium; by this test $\frac{1}{500000}$th grain of calcium can be detected.

(4) Silico-fluoric acid yields precipitate.

STRONTIUM. Symbol Sr. Atomic weight 87.2.

Occurrence: As a carbonate in the mineral strontianite; as a sulphate in celestite; as a chloride or sulphate in many brine springs, mineral waters, sea-water, etc., and in the ash of the plant *Fucus vesiculosus.*

Preparation and properties: By electrolysis of the fused anhydrous chloride. It is a yellow, malleable metal, harder than calcium, melting at a red heat and oxidizing quickly in the air. It burns when heated and decomposes water at common temperatures.

Strontium chloride, $SrCl_2$, is prepared by the action of hydrochloric acid on strontium carbonate. The chief use of the salt is to produce the red fire of pyrotechnics.

For this purpose **strontium nitrate, $Sr(No_3)_2$,** is the most serviceable, as it furnishes oxygen.

Red fire mixture:

Strontium nitrate . .	63	per cent.
Sulphur	18	"
Potassium chloride . .	16	"
Lampblack	3	"

Tests for strontium: (1) The strontium salts tinge the flame carmine-red.

(2) The spectrum presents five or six lines of red.

(3) It gives no precipitate with silico-fluoric acid.

(4) Sulphuric acid gives an insoluble precipitate.

BARIUM. Symbol Ba. Atomic weight 136.8

Occurrence: It occurs mainly as a sulphate, the mineral *barite;* and as the carbonate, *witherite.*

Preparation and properties: It is prepared by electrolysis from the fused chloride, and is a pale yellow mass, easily tarnishing, and malleable. It gradually oxidizes in the air and decomposes water.

Barium chloride, $BaCl_2$, is the residue from the evaporated solution of the natural carbonate in hydrochloric acid:

$$BaCO_3 + 2HCl = BaCl_2 + H_2O + CO_2.$$

Its crystals are transparent, colorless, and four-sided, soluble in water. The solution is used as a test for sulphuric acid or sulphates, and precipitates a heavy white powder of barium sulphate:

$$H_2SO_4 + BaCl_2 = BaSO_4 + 2HCl;$$
$$Na_2SO_4 + BaCl_2 = BaSO_4 + 2NaCl.$$

The **hydroxide, $Ba(OH)_2,8H_2O$,** is soluble in 20 parts of cold water or 2 parts of hot water. The solution is highly alkaline to test-paper and is a valuable reagent, as it is instantly rendered turbid by the smallest traces of carbonic acid.

Barium nitrate: It is *produced* by the action of nitric acid on barium carbonate. It occurs as transparent, colorless, anhydrous crystals soluble in eight parts of cold or three parts of hot water.

It is *used* in the manufacture of *green fire,* the composition of which is:

Barium nitrate		60	per cent.
Sulphur	about	21	"
Potassium chlorate		15	"
Lampblack		4	"

Barium sulphate, $BaSO_4$, occurs as a heavy spar or barite, often beautifully crystallized. Sulphuric acid and any soluble barium salt produce it as a fine white powder. It is one of the most insoluble salts known. The precipitated salt is used as a substitute for white lead in the manufacture of oil paints known as "*blanc fixe*." It is used to glaze the surface of cards.

Tests for barium: (1) The salts tinge the blowpipe flame green.

(2) The spectrum shows a series of bright lines in the green and fainter bands in the red.

(3) Silico-fluoric acid gives a white precipitate.

The soluble salts of barium are poisonous.

III. METALS OF THE MAGNESIUM GROUP.

Beryllium,	Zinc,
Magnesium,	Cadmium.

These metals are all dyads, and burn brightly when heated in the air. They decompose water at high temperatures. They dissolve readily at ordinary temperatures in hydrochloric and dilute sulphuric acids with the evolution of hydrogen. Each forms only one oxide and one sulphide. The oxides, excepting that of magnesium, which is slightly soluble, are insoluble in water.

The sulphates are soluble in water; the normal carbonates and phosphates are insoluble.

BERYLLIUM or **GLUCINUM**. Atomic weight 9. Symbol **Be**.

Occurrence: This rare element occurs as a *silicate*, either alone, as in phenacite, with other silicates, as in beryl and a few other minerals, and as *aluminate* in chrysoberyl.

Preparation: It is produced by the action of metallic sodium on the vapor of the chloride of beryllium.

Characteristics: It is a white metal, specific gravity 2.1, which may be forged and rolled. Its melting-point is below that of silver; it does not decompose water at a boiling heat;

it is soluble in sulphuric and hydrochloric acids with the evolution of hydrogen. The compounds are not medicinally important. The mineral beryl is valuable as a gem. When green it is known as an *emerald,* while the bluish-green is termed *aqua marine.*

MAGNESIUM (Magnesia, a town in Asia Minor).
Symbol **Mg.** Atomic weight 23.94.

Occurrence: *In many silicates,* as talc, serpentine, etc.; as a *carbonate, magnesite; double carbonate of calcium and magnesium,* dolomite, often forming entire mountain ranges; as an *aluminate,* in spinel; as *soluble salts,* in mineral and sea-waters; as a *carbonate* and *phosphate,* in the bodies of plants and animals.

Preparation: (1) Electrolysis of fused magnesium chloride; (2) By reducing magnesium chloride with metallic sodium.

Characteristics: It is a bluish-white metal, specific gravity 1.75, melting at a red heat, and volatilizing at high temperatures. It is brittle at ordinary temperatures, malleable at a heat little below redness. It tarnishes in moist air, is easily combustible, and burns with a dazzling white light, emitting dense white clouds of solid oxide, MgO. It produces a continuous spectrum containing a large proportion of the more refrangible rays, hence well adapted for photography.

Magnesium chloride, $MgCl_2$, occurs in sea-water, many brine springs, and in salt beds. It is prepared from hydrochloric acid and magnesium carbonate in the presence of ammonium carbonate. It is also produced in large quantities from the salt beds at Stassfurt. It is white, crystalline, deliquescent, and soluble in water and alcohol.

Magnesium oxide, MgO, *magnesia,* is prepared by exposure of the hydrocarbonate to a full red heat. It is a soft, white powder, slowly attracting moisture and carbon dioxide from the air. It is soluble in 5000 parts of water at 15.5° C., and is used as a face powder and medicinally.

Magnesium sulphate, $MgSO_4,7H_2O$, *Epsom salt,* occurs in sea-water and mineral springs.

It is *prepared* in large quantities by the action of sulphuric acid on dolomite or magnesite. In the former cases it is separated from the almost insoluble calcium sulphate by filtration.

Its crystals, soluble in an equal weight of water, have a nauseous, bitter taste, and possess purgative qualities. It forms double salts with potassium and ammonium.

The **double phosphate of magnesium and ammonium, $Mg(NH_4)PO_4,6H_2O$,** sometimes forms *urinary calculi*, and may be converted by heat into the pyrophosphite of magnesium, $Mg_2P_2O_7$.

The magnesium silicates: *Chrysolite*, $2(MgFe)O,SiO_2$, used for ornamental purposes;

Sepiolite (*meerschaum*), $2MgO,3SiO_2$, used for pipe-bowls and cigar-holders.

Talc, $4MgSiO_3,SiO_2,4H_2O$, used for fire-stones and as a powder for diminishing friction;

Serpentine, a combination of silicate and hydroxide: a "fibrous" variety (chrysolite) is used for the manufacture of fire-proof fabrics, ropes, etc.

Jade, *augite*, and *hornblende* are other common minerals containing magnesium as a silicate.

Normal carbonate of magnesium, $MgCO_3$, occurs as a mineral, magnesite, principally at the island of Eubœa. On account of its infusibility it is used as a refractory material. Magnesia alba is a compound of carbonate and hydroxide.

Tests for magnesia: (1) With any phosphate in the presence of ammonia it yields a white precipitate of ammonium magnesium phosphate, soluble in acids.

(2) The salts are white, acquiring a pink tint when moistened with cobaltic nitrate and heated before the blowpipe.

ZINC. Symbol Zn. Atomic weight 64.9.

It **occurs** in many minerals.

Its chief **ores** are the oxide, *zincite* and *franklinite;* the sulphide, *sphalerite;* and the carbonate, *smithsonite*.

Preparation: The ores are first roasted and then heated in earthenware tubes or fire-clay crucibles with coke or charcoal.

Metallic zinc is set free and caught in suitable vessels, remelted, and cast into bars known as "*spelter.*"

Properties: Zinc is a bluish-white metal, tarnishes slowly in air, has a lamellar, crystalline fracture, and of specific gravity 6.8 to 7.8. It is brittle under ordinary circumstances, and malleable between 120° and 150° C., at which temperature it may be rolled or hammered, after which treatment it retains its malleability when cold. The sheet-zinc of commerce is thus made. At 205° C. it becomes brittle again and may be pulverized. This powder when heated, if air be present, ignites and burns with a luminous green flame. It melts at 423° and boils at 1035° C. Dilute acids dissolve zinc readily, liberating hydrogen.

Uses: (1) As a protecting cover for iron, known as "*galvanized iron*": iron articles, such as plates, rods, wire, etc., are cleansed in dilute sulphuric acid (called "pickling"), then dipped into molten zinc, and thus become coated;

(2) As sheet-zinc for fire-screens, roofing, etc.;

(3) As granulated zinc for generating hydrogen (prepared by pouring a stream of molten zinc into cold water);

(4) As an ingredient of important alloys: *brass* is an alloy of zinc and copper; *German silver*, an alloy of zinc, nickel, and copper.

(5) In batteries.

Zinc chloride, $ZnCl_2$, is prepared by dissolving zinc in hydrochloric acid and evaporating to dryness. The residue, a white, translucent, pasty solid, is very deliquescent and soluble in water and alcohol.

It is *used*: in surgery as a caustic; in embalming bodies; in tinning and soft-soldering copper and iron; as an antiseptic; and in the preservation of wood from decay, called "*Barnettizing.*" The process consists in enclosing wood in strong iron cylinders, exhausting the air, and saturating the wood with $ZnCl_2$ under strong pressure. Copper sulphate, mercuric chloride, coal-tar, creasote, etc., are also employed in the same way as preservatives.

Zinc oxide, ZnO, is found as mineral zincite at Franklin, N. J. The red color is due to the presence of manganese.

Preparation : (1) By burning zinc;
(2) By heating the carbonate :

$$ZnCO_3 + \text{heat} = ZnO + CO_2.$$

Properties and uses : It is a white, tasteless powder, yellow when heated, insoluble in water, soluble in acids, and used as a pigment, called "*zinc white.*"

Zinc sulphate, $ZnSO_4$ (*white vitriol*), occurs as the mineral goslarite. It may be obtained :
(1) By the action of sulphuric acid on zinc :
(2) By roasting sphalerite (*blende*) :

$$ZnS + O_4 = ZnSO_4.$$

Properties: It has an astringent, metallic taste; it crystallizes as $ZnSO_4,7H_2O$; is soluble in two and a half parts of cold water; and forms double salts with potassium and ammonium. It is used *medicinally as an emetic.*

Zinc carbonate, $ZnCO_3$, occurs as a mineral, smithsonite. The white precipitate formed by adding a solution of alkaline carbonate to a soluble zinc salt is a mixture of carbonate and hydrate. When heated to redness it forms a pure zinc oxide.

Zinc sulphide, ZnS, occurs as the mineral *sphalerite,* also called *blende* and *black-jack.*

A hydrated sulphide, ZnS,H_2O, is formed on adding a solution of alkaline sulphide to a soluble zinc salt.

Tests for zinc compounds: (1) *Sulphuretted hydrogen,* H_2S, gives a white precipitate in neutral solutions, but not in acid solutions;

(2) Ferrocyanide of potassium gives a white precipitate;

(3) On charcoal, with sodium carbonate, before the blowpipe, they give a yellow coat of ZnO, which whitens on cooling. If this coat be moistened with cobaltic nitrate and strongly heated, a fine green color is produced.

CADMIUM. Symbol **Cd.** Atomic weight 112.3.

Occurrence : This comparatively rare metal, accompanying ores of zinc, also occurs as the mineral greenockite, which is the sulphide.

Properties : It closely resembles zinc, is more volatile, and distils over first in the preparation of that metal. It is bluish-white and malleable; specific gravity 8.7. It tarnishes but little in air; burns when strongly heated; melts at 320° F., boils at 860°, forming a vapor having only half the density indicated by its atomic weight. Hence its molecule consists of a single atom. Its compounds are analogous to those of zinc.

Uses : Excepting the sulphide, CdS, which is used as a pigment, and the iodide, CdI, employed in photography, the cadmium compounds are but little used.

IV. METALS OF THE LEAD GROUP.

Lead and thallium : These metals are soft, heavy, and form basic oxides having an alkaline reaction. Thallium in many of its properties closely resembles the alkali metals; and lead resembles the metals of the alkaline earths in forming an insoluble carbonate and sulphate; but lead and thallium are distinguished from both these groups by the black color and insolubility of their sulphides, and from the sparing solubility of their bichlorides.

LEAD (**PLUMBUM**). Symbol **Pb.** Atomic weight 206.4.

Occurrence : It occurs in many minerals, principally as galenite, galena, or lead sulphate, and cerussite, or lead carbonate.

Preparation : There are four methods for the metallurgical production of lead from its ores:

(1) *Roasting and reaction* (foreign practice). The sulphide is roasted in a reverberatory furnace to form a sulphate and oxide, and the reaction of these salts on each other produces metallic lead:

$$2PbO + PbS = SO_2 + 3Pb \text{ and } PbSO_4 + PbS = 2SO_2 + 2Pb.$$

The presence of more than 4 per cent. of SiO_2 debars this method.

(2) *Roasting and reduction* (the type of the U. S. practice). The sulphide is roasted in a reverberatory furnace to form the oxide and then combined with silica to form the silicate. The reduction of metallic lead from this silicate is accomplished in a blast-furnace by reduced iron ore.

(3) The method of roasting and precipitation is the reduction of the sulphide by means of metallic iron :

$$PbS + Fe = Pb + FeS.$$

This process is of limited applicability, mainly foreign.

(4) The *mixed method* is based on a combination of the foregoing reactions. Its limited applicability is also mainly foreign.

The lead produced by these methods often contains antimony and other metals, which render it *hard*. These impurities may be removed by oxidation in a reverberatory furnace, producing *soft* lead. Should the purified lead contain silver in sufficient quantity to render it worth extracting, it is separated as described under Silver.

A great part of the silver produced in the world is obtained from argentiferous galena.

Properties: It is a bluish-white, soft, malleable metal. It may be drawn out into coarse wire or hammered into plate, but has little elasticity or tenacity. It melts at 334° F. and boils and volatilizes at higher temperatures. When freshly cut the brilliant metallic lustre quickly tarnishes in moist air, particularly if carbonic acid be present. It rapidly absorbs oxygen when molten. By slow cooling it may be crystallized in octahedral crystals. Dilute acids, excepting nitric, act but slowly upon lead.

The salts of lead are all poisonous, even the slightest traces taken into the system daily will in time accumulate and cause serious illness ; hence it is very important to prevent the presence of these salts in drinking-water. Pure water free from air does not attack lead. When air is present the oxide of lead is formed, and this dissolving in the water exposes successive portions of the metal to oxidation.

Waters containing *nitrates, chlorides, sulphates*, or much *carbonic acid* gradually take lead into solution. Hard waters, or waters containing either *sulphates* or *carbonates*, soon form a thin insoluble coating on the surface of lead pipe, thus protecting it from further oxidation. Such waters therefore are relatively safe.

Uses: It is used as sheet-lead in sulphuric acid chambers; as lead pipe sometimes tin-lined; as plumbers' solder, which is an alloy of 2 parts lead and 1 part tin; and in the manufacture of shot; also in type-metal, which contains a little antimony to give sharp edges to the cast.

Lead dichloride, **$PbCl_2$**, is prepared from common salt or hydrochloric acid mixed with lead nitrate or acetate. It is a heavy white precipitate soluble in 33 parts of boiling water, from which solution it crystallizes by cooling into needle-shaped crystals.

Lead perchloride, $PbCl_4$ (probably), is formed from a solution of lead dioxide and strong hydrochloric acid.

The **oxychlorides** are:

$Pb_3Cl_2O_2$,	the mineral mendipite;
Pb_2Cl_2O,	Pattison's white oxychloride;
$PbCl_2,7H_2O$,	patent yellow, or Turner's yellow.

The two latter oxychlorides are used as pigments.

Lead iodide is prepared from potassium iodide and lead nitrate; it is a bright-yellow powder, soluble in boiling water, and crystallizes in beautiful yellow iridescent spangles.

Diplumbic oxide, Pb_2O, or *suboxide*, is prepared by heating the monoxide in a retort. It is a gray, pulverulent substance, rapidly absorbing oxygen.

Lead monoxide, PbO, *litharge, massicot*, may be obtained:

(1) By direct oxidation of metallic lead;

(2) By heating the carbonate to a dull redness.

It is a delicate straw-colored powder, slightly soluble in water, and yielding an alkaline solution. It melts at a red heat, and tends to crystallize on cooling.

In the melted state it attacks and dissolves siliceous matter with great avidity, often penetrating an earthen crucible in a few minutes. It is readily reduced by heating with organic substances, and forms a large class of salts, called *plumbic salts.* It is used medicinally and in the manufacture of glass and glazing earthenware.

The **sesquioxide, Pb_2O_3,** is a reddish-yellow powder.

The **triplumbic tetroxide, Pb_3O_4,** *red lead*, the composition of which is not constant, is obtained by exposing the monoxide for a long time at a red heat to the action of air. It is a brilliant-red powder, decomposing at a red heat with the evolution of oxygen. As a pigment it is a cheap substitute for vermilion. It is used in the manufacture of flint-glass and in the preparation of some cements.

Lead dioxide, PbO_2, brown dioxide, the residue from digesting red lead in nitric acid.

Its great affinity for sulphurous oxide, SO_2, renders it useful as an absorbent for this gas:

$$PbO_2 + SO_2 = PbSO_4.$$

Lead sulphate, $PbSO_4$, occurs native as the mineral anglesite. In the laboratory it may be prepared by the action of sulphuric acid on any soluble lead salt, and is then precipitated as a white powder soluble in alkalies.

The formulæ for **lead nitrate, lead phosphate**, and **lead acetate** are:

$$Pb(NO_3)_2,\ Pb_3(PO_4)_2,\ Pb(C_2H_3O_2)_2, \text{ respectively.}$$

Normal lead carbonate, $PbCO_3$, occurs as the mineral cerussite, but it may be artificially produced:

(1) By a cold solution of lead acetate and ammonium carbonate;

(2) By passing carbon dioxide through a dilute solution of lead acetate.

Basic carbonates of lead: Lead forms several basic carbonates, the most important of which is *white lead*, $2PbCO_3,3H_2O$.

It is manufactured on a large scale for pigment. There are several processes of preparation, the more important being:

(1) *The Old Dutch Method.*—Jars containing sheet-lead are for a long time exposed to the action of carbon dioxide, which is produced by the fermentation of spent tan-bark or sawdust mixed with a little vinegar.

The chemistry of this process is as follows: The heat generated from the fermentation causes the acetic acid of the vinegar to be given off as vapor, which attacks the lead, forming a basic acetate. The action of CO_2 from the fermentation converts this acetate into a carbonate.

(2) By dissolving lead oxide in a normal acetate solution, forming a basic acetate, from which lead carbonate is precipitated by passing carbon dioxide through the solution.

Properties and uses: It is a heavy, white, amorphous powder, showing, under the microscope, round, transparent globules, measuring from one to four hundred thousandths of an inch in diameter. It is used as a pigment, often adulterated with barium sulphate and zinc oxide.

Although white lead is by far the most brilliant of the white paints, its use is somewhat objectionable, as it is readily blackened by sulphuretted hydrogen and is poisonous to painters who handle it.

Lead sulphide, PbS, or *galena,* occurs as the mineral galenite, the most important ore of lead, in crystals of the isometric system, generally cubes, of a bluish-gray color; as *artificial crystals* by passing sulphur vapor over metallic lead; or as a *black amorphous precipitate* by passing sulphuretted hydrogen through a solution of lead salt in the presence of hydrochloric acid.

Tests for lead salts: (1) *Caustic potash* or *soda* yields a white precipitate, freely soluble in an excess of caustic;

(2) *Ammonia* gives a similar white precipitate, not soluble in excess;

(3) *Carbonates of potassium, sodium,* and *ammonium* precipitate lead carbonate, insoluble in an excess;

(4) *Sulphuric acid* or *sulphate* gives a white precipitate, insoluble in an excess;

(5) *Hydrogen sulphide* and *ammonium sulphide* yield an amorphous black precipitate of sulphide;

(6) *Charcoal* and *sodium carbonate* before the blowpipe yield the malleable metal.

THALLIUM. Symbol Tl. Atomic weight 203.6.

Thallium is found in specimens of iron and copper pyrites, in zinc-blende in *lepidolite*, and in the Neuheim salt-works. It is usually obtained from the tubes or burners in sulphuric-acid works. It is a heavy metal resembling lead, soft and malleable. It furnishes the spectrum with a single green line, whence its name, *thallos*, green. It is univalent in the thallous and trivalent in the thallic compounds. It forms two oxides, Tl_2O and Tl_2O_3, with corresponding chlorides, iodides, bromides, and oxygen salts. Most of its salts are poisonous. It was discovered by Crookes in 1861.

V. METALS OF THE COPPER GROUP.

Copper, mercury, and silver: Each of these metals forms several oxides and two series of salts, the constitution of which is best represented, as will be presently explained, by regarding the metals as dyads, although copper and silver figure in Mendelejeff's series as monads. These metals do not decompose water at a red heat; they are precipitated from their solutions in the metallic state by zinc, iron, and the more oxidizable metals. Their lower chlorides are insoluble in water.

COPPER (CUPRUM). Symbol Cu. Atomic weight 63.1.

Occurrence: Widely diffused in the mineral kingdom; its important ores are the *native copper* of Lake Superior; the *sulphide* as chalcocite, or with iron and sulphur as chalcopyrite and bornite; the *oxide* as cuprite; and the *carbonate* as malachite and azurite.

It is **industrially prepared**: (1) From the *native* mineral by purification (termed "*refining*") in the reverberatory furnace.

(2) From the sulphides of iron and copper (its principal source) by a rather complicated process, essentially as follows:

The ore is roasted, by which much of the iron sulphide is converted into the oxide. The product is then put through a furnace, the oxide of iron combining with the silica of the ore, forming a fusible slag; while the copper, sulphur, and the remaining iron combine to form a fusible "matte." The slag, being much lighter than the "matte," is easily separated. When nearly all the iron and sulphur have been eliminated by a repetition of this operation the product is "black copper," containing about 5 per cent. of impurities, mainly iron, from which it is freed by a refining operation in a reverberatory furnace.

(3) From the *oxides* and *carbonates* it is easily reduced in a shaft furnace by carbonaceous material to black copper, which is then submitted to the refining operation of the reverberatory furnace.

(4) Copper has been extracted to a minor extent by lixiviating methods. It can also be prepared by electrolytic deposition from its solutions, or by reduction of its oxide by hydrogen.

Properties: Copper is of a reddish color, specific gravity 8.95, very malleable, ductile, and tenacious; an excellent conductor of heat and electricity; melts at a bright-red heat; slightly volatile at high temperatures, imparting a green tinge to flame; unaltered in dry air, but if exposed to moist air it becomes covered with a strong adherent green crust of carbonate; heated to redness in air it becomes coated with a black scale of oxide. It is but slightly acted upon by dilute sulphuric and hydrochloric acids; soluble in hot sulphuric acid, evolving sulphurous oxide fumes, and in nitric acid evolving fumes of nitrogen dioxide.

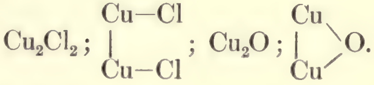
The **cupric compounds** are bivalent and stable, consisting of 1 atom of metal combined with 2 atoms of a univalent or 1 atom of a bivalent negative radical, viz.,

$$Cu = Cl_2;\ Cu = O;\ Cu = (NO_3)_2;\ Cu = SO_4, \text{ etc.}$$

It also forms another series, the **cuprous compounds**, in which it may be regarded as univalent, viz.,

$$Cu—Cl;\ Cu_2O;$$

or bivalent, as :



$$Cu_2Cl_2;\ \begin{array}{l} Cu-Cl \\ | \\ Cu-Cl \end{array};\ Cu_2O;\ \begin{array}{l} Cu \\ | \\ Cu \end{array}\!\!>O.$$

These "*ous*" compounds are very unstable and easily converted into the "*ic*" compounds.

Cupric chloride, $CuCl_2$, is obtained by the action of copper oxide and hydrochloric acid. It crystallizes in green crystals, $CuCl_2,2H_2O$, and is very soluble in water and alcohol.

Cuprous chloride, Cu_2Cl_2, is prepared :

(1) By copper in chlorine gas ;

(2) By precipitation from solutions of cupric chloride by stannous chloride :

$$2CuCl_2 + SnCl_2 = Cu_2Cl_2 + SnCl_4.$$

It is a white fusible substance, easily oxidized, and slightly soluble in water.

Copper monoxide, CuO, *cupric oxide*, black oxide of copper, is prepared :

(1) By heating metallic copper with an excess of air ;

(2) By decomposing the nitrate by heat.

Cupric salts mixed with caustic alkalies in excess yield bulky pale-blue precipitates of hydrated cupric oxide, CuH_2O_2. It is soluble in acids and colors glass green.

Cuprous oxide, *suboxide of copper* or *red oxide*, occurs as the mineral cuprite, and may be obtained :

(1) By heating black oxide and copper filings ;

(2) By boiling a solution of sulphate of copper, caustic potash, and grape-sugar.

Properties : As a native mineral, when crystallized, it has a beautiful blood-red color ; is soluble in an excess of hydrochloric acid ; is decomposed by most oxyacids, forming cupric salts and metallic copper. It imparts a beautiful red color to glass.

Sulphate of copper, *blue vitriol,* is found sparingly as the mineral chalcanthet, and is prepared by treating cupric oxide in sulphuric acid. It forms large blue triclinic prisms of $CuSO_4,5H_2O$, soluble in 4 parts of cold to 2 parts of hot water, which becomes a white powder when anhydrous. It forms double salts with potassium and ammonium, and is used mainly for gravity batteries.

Cupric nitrate, $Cu(NO_3)_2,3H_2O$, is formed by treating copper with nitric acid. Its deep blue crystals are soluble, deliquescent, and highly corrosive.

Cupric carbonate occurs native, as the minerals azurite and malachite. Azurite is deep blue in color, malachite a deep green. It is sometimes used for jewelry and ornaments. The artificial green carbonate is used as a pigment.

Cupric sulphide, CuS, occurs sparingly as the mineral covellite. It is prepared by passing hydrogen sulphide through a solution of a cupric salt.

Cuprous sulphide, Cu_2S, occurs as the mineral chalcocite. It is prepared from metallic copper by heating with vapor of sulphur.

Tests for the copper compounds: (1) *Ammonia* precipitates the hydroxide, soluble in an excess, yielding a deep blue solution;

(2) *Potassium and sodium carbonates* give precipitates of cupric carbonate insoluble in an excess;

(3) *Ammonium carbonate* yields the same, but soluble in an excess to a deep blue solution;

(4) *Potassium ferrocyanide* gives a red-brown precipitate of cupric ferrocyanide;

(5) *Hydrogen sulphide* and *ammonium sulphide* give black cupric sulphide insoluble in ammonium sulphide;

(6) *Metallic iron* or *zinc* immersed in a solution of a copper salt precipitates metallic copper;

(7) They impart a green color to flame;

(8) With borax they yield, in the oxidizing flame, a green color when hot, blue when cold; in the reducing flame the bead becomes red and opaque;

(9) They can be reduced to metallic copper when mixed with sodium carbonate or potassium cyanide and heated.

The alloys of copper: *Brass,* copper with about 30 per cent. zinc;

Gun-metal, copper with about 10 per cent. tin;

Bell and *speculum metals,* copper with larger per cent. of tin;

Bronze, copper with 10 per cent. of zinc, tin, and lead.

Uses: Copper is extensively used in electrotyping; in constructing electrical apparatus; as telegraph wires; as a sheathing for ships; as coins, etc. Its green salts, the arsenite and the double salt arsenite and acetate, form the pigments *Scheele's green* and *Paris green.* The latter is extensively used as an insect destroyer, particularly for the Colorado beetle or potato bug.

SILVER (**ARGENTUM**). Symbol **Ag**. Atomic weight 107.66.

It **occurs** in a *metallic state* as a *sulphide, argentite;* and as a sulphide of arsenic, *proustite*, and with sulphide of antimony, *pyrorgyrite;* as *chloride, iodide, bromide,* and *telluride,* and with other minerals as argentiferous galena.

It is **prepared** by a great variety of processes, as: (1) By fusion of silver-bearing material with lead ores and subsequent separation;

(2) By fusion with copper ores and subsequent separation;

(3) By amalgamation;

(4) By lixiviation.

When with *lead* the silver is obtained as argentiferous lead, by a regular process described under Lead. The product is called "*base bullion*" or "*work lead.*" The silver is separated therefrom by the process of zinc desilverization, based on the principle that silver has a greater affinity for zinc than for lead. Metallic zinc is added to the molten lead and is itself melted. By lowering the temperature the zinc solidifies, as its melting-point is higher than that of lead, and forms with some silver and lead a crust or scum on the surface of the lead. Only a small amount of zinc is necessary to extract practically all the silver. The silver is separated from the *zinc* by placing them in a retort with charcoal. The zinc distils over and is condensed, leaving the silver with a very small amount of zinc and a little lead in the retort. This silver is then "cupelled," the lead and zinc being oxidized and driven off, and the silver remaining in the cupel almost absolutely pure.

When with *copper* the silver is generally obtained from the black copper by *electrolysis,* or from a solution in acids. From a rich matte it is obtained by roasting the silver sulphide to sulphate and leaching with hot water, from which solution it is precipitated by metallic copper.

When silver does not occur with lead or copper ores, or lead and copper ores are not available, the process of *amalgamation* is employed. The ore is finely ground and made into a thin paste with water. Mercury is then introduced, which unites with the silver, forming an amalgam, from which the silver is obtained by distillation. The distilled mercury condenses and is used again.

When silver ores do not contain copper or lead enough to smelt, and are too poor to pay for amalgamation, one of the processes of *lixiviation,* of which there are several, is sometimes used:

The roasting of the ore with salt forms silver chloride. Then follows its solution in thiosulphate of sodium (called hyposulphite of sodium), from which it is precipitated as a sulphide.

In the reduction of a silver salt by means of metallic zinc the gray and spongy silver obtained may be purified by washing with acidulated water.

Silver—properties: It is white and lustrous; specific gravity 10.512; exceedingly malleable and ductile; the best conductor of heat and electricity. It melts at 1040° C., and may be vaporized and distilled at very high temperatures. Its vapor has a bright blue color. Molten silver absorbs many times its bulk of oxygen from the air and gives it out again when cooling, sometimes so suddenly as to cause explosive sputterings, called "spitting." This absorption of oxygen is prevented by the presence of 2 per cent. of copper. Silver is but slightly attacked by hydrochloric acid; but is soluble in hot sulphuric acid, and readily soluble in nitric acid, even dilute. It is unaltered by air or moisture. The tarnishing of silver is due to the formation of a sulphide film from the presence of sulphuretted hydrogen in the air.

Argentic chloride, $AgCl$ or Ag_2Cl_2, occurs as a mineral: *Cerargyrite, horn silver;* and with *bromine* and *iodine, bromargyrite, embolite,* and *iodyrite.*

Preparation and properties: It is the result of union between any chloride and a silver salt. It is a white curdy precipitate; insoluble in water and nitric acid, soluble in 200 parts of concentrated HCl. It melts when heated, forming a gray crystalline mass, which cuts like horn and is decomposed by light. It is reduced by metallic zinc or iron and is easily soluble in ammonia, in a solution of common salt, or potassium cyanide.

Argentous chloride, Ag_4Cl_2, is formed by the action of hydrochloric acid on argentous oxide. Heat or ammonia easily decomposes it into argentic chloride. The sensitiveness of the silver salts of bromine, iodine, and fluorine to light makes them useful in photography.

Argentic oxide, Ag_2O, is prepared by adding caustic potash to silver nitrate:

$$2AgNO_3 + 2KOH = Ag_2O + 2KNO_3 + H_2O.$$

It is a strong base, forming salts isomorphous with alkali metals and giving pale brown precipitates. It is soluble in ammonia and to a slight extent in water, yielding an alkaline solution. It neutralizes acids; is decomposed by a red heat with the liberation of oxygen, leaving the silver as a metallic sponge.

Silver sulphate, Ag_2SO_4, prepared by boiling metallic silver in concentrated sulphuric acid, or by the precipitation of a silver nitrate solution with an alkaline sulphate:

Silver dithionate, $Ag_2S_2O_6$;
Silver thiosulphate, $Ag_2S_2O_4$.

Silver nitrate, $AgNO_3$, or lunar caustic, is prepared by dissolving metallic silver in nitric acid. It separates from the solution in colorless anhydrous transparent tables, soluble in an equal weight of cold or in one-half its weight of boiling water and also in alcohol. It fuses when heated and blackens when exposed to light in the presence of organic matter. It is used in cautery, indelible inks, hair dye, and as a reagent test for hydrochloric acid.

Silver carbonate, Ag_2CO_3, is prepared by the action of sodium carbonate on silver nitrate. It is a white insoluble substance, blackened and decomposed by boiling.

Silver sulphide, Ag_2S, occurs as the mineral *argentite*. It may be prepared by the action of hydrogen sulphide on a silver solution, or by melting silver and sulphur together. It is a gray, soft, malleable substance, a strong sulphur base, combining with the sulphides of arsenic and antimony.

Cyanide of silver, AgCN, is formed as a precipitate if potassium cyanide be added to a solution of silver nitrate. It dissolves on the addition of more potassium cyanide. This solution is extensively used in silver-plating.

Process of silver-plating: In a solution of silver cyanide, variously prepared, the object to be plated is immersed with a bar or plate of pure silver. The latter is connected by wire to the negative element of a battery, while the object to be plated is connected with the positive. Electrolysis takes place, dissolving the silver from the bar or plate and depositing a thin coat or film on the object. The process is carried on until the silver is deposited to a desired thickness. After this the plated article is washed and polished. The same general method is employed, but with different solutions, when plating with gold, copper, platinum, or nickel.

Tests for the silver compounds: (1) *Hydrochloric acid* gives a white curdy precipitate, which is soluble in ammonia, darkens by exposure to light, and is insoluble in nitric acid;

(2) *Iron*, *copper*, or *mercury* reduces a silver salt to a metallic state;

(3) *Hydrogen sulphide* gives a black precipitate of silver sulphide, insoluble in *ammonium sulphide;*

(4) *Alkaline carbonates* give white precipitates soluble in ammonia;

(5) *Sodium phosphate* gives a yellow precipitate;

(6) *Potassium chromate* or *bichromate* gives a red-brown precipitate.

MERCURY (HYDRARGYRUM). Atomic weight 199.8. Symbol **Hg**.

Mercury, often called *quicksilver,* **occurs** mainly as sulphide in the mineral cinnabar; as *metallic globules* disseminated through the *sulphide, cinnabar;* also in unimportant amounts in other ores. It may be prepared in furnaces by reducing the ore with iron or lime, the volatilized mercury being condensed in suitable chambers or pipes, and sent into commerce in wrought-iron bottles holding 75 pounds each.

Properties: Mercury is a silver-white lustrous metal, specific gravity, 13.596, liquid at ordinary temperatures, solidifying at —39.5° C., in which state it is soft and malleable. It boils at 357° C., yielding a vapor of density 100, showing that the mercury, like the cadmium, molecule consists of *one atom.* It volatilizes to a considerable extent at all temperatures above 20° C., but is unaltered in air at common temperatures. When heated to near its boiling-point it absorbs oxygen. It is insoluble in HCl or dilute H_2SO_4, but soluble in concentrated H_2SO_4 and HNO_3. It combines directly with chlorine, bromine, iodine, and sulphur.

Mercuric chloride, $HgCl_2$ (corrosive sublimate), is prepared:

(1) By metallic mercury in chlorine gas;

(2) By mercuric oxide in hot hydrochloric acid and crystallized by cooling;

(3) By subliming a mixture of equal parts of mercuric sulphate and common salt:

$$HgSO_4 + 2NaCl = HgCl_2 + Na_2SO_4.$$

Properties: It is a white transparent crystalline mass, which melts at 265° C., boils at 295° C., and is soluble in 16 parts of cold or 3 parts of boiling water; also soluble in alcohol and ether. It combines with a great number of other metallic chlorides, absorbs ammonia gas with great avidity, forming $HgCl_2.NH_3$. It forms insoluble compounds with many of the azotized organic principles, as albumin, etc. It is probable that to this quality its strong *antiseptic* properties are due. Animal and vegetable substances are preserved by it according to Kym's methods of preserving timbers and cordage. In case of poisoning, albumin is an excellent antidote.

Mercurous chloride (calomel), **HgCl** or Hg_2Cl_2, is prepared:

(1) By a solution of mercurous nitrate in a dilute solution of common salt;

(2) By subliming an intimate mixture of dry mercuric sulphate, mercury, and salt:

$$HgSO_4 + Hg + 2NaCl = Hg_2Cl_2 + Na_2SO_4.$$

Properties: It is a heavy, white, insoluble, tasteless powder. It vaporizes below redness, condensing to a yellow-white crystalline mass, soluble in boiling hot nitric acid. It is apt to contain some corrosive sublimate, a dangerous contamination when calomel is used for medicinal purposes. Recent experiments tend to show that the true formula is HgCl. It is much used *medicinally.*

Mercuric iodide, HgI_2, is prepared from a solution of mercuric chloride and potassium iodide. Yellow at first, it then becomes a scarlet dimorphous precipitate. It is employed *medicinally.*

Mercurous iodide, Hg_2I_2, is formed from mercurous nitrate and potassium iodide. A greenish-yellow precipitate results from their union. *Medicinally* it is useful.

Mercuric oxide, HgO, red oxide of mercury, red precipitate, is prepared by:

(1) Oxidizing mercury at high temperature;

(2) Decomposing the nitrate by heat;

(3) Excess of caustic potash added to a solution of corrosive sublimate.

Properties: Red color; slightly soluble in water, giving alkaline reaction and metallic taste; highly poisonous; decomposed by heat into mercury and oxygen. A yellow or amorphous form is used with oleic acid for skin diseases.

Mercurous oxide, Hg_2O, *suboxide* or *gray oxide of mercury:*

(1) Caustic potash added to mercurous nitrate;

(2) Digesting calomel with caustic potash. It is a grayish-black heavy powder insoluble in water and slowly decomposed by the action of light.

The preparations known as *blue-pill*, *gray ointment*, *mercury with chalk*, etc., contain merely the finely divided metal.

Mercury and *cold dilute* nitric acid yield the **mercurous nitrate,** while *hot concentrated* nitric acid and mercury yield the **mercuric nitrate.**

Mercuric sulphate, $HgSO_4$, is derived from mercury and hot concentrated sulphuric acid, and is used in some forms of galvanic batteries.

Mercurous sulphate, Hg_2SO_4, is prepared from mercurous nitrate and sulphuric acid.

Mercuric sulphide, HgS, occurs as the mineral cinnabar, the principal source of mercury. It is also formed:

(1) By an excess of sulphuretted hydrogen passed through mercuric nitrate or chloride;

(2) By subliming a mixture of 6 parts of mercury and 1 part of sulphur.

Properties and uses: (1) A black precipitate, changed by sublimation to a dark red and crystalline form.

(2) A red powder called vermilion. Its beauty of tint depends upon its fineness of division. Heated in air it decomposes to metallic mercury and sulphur dioxide. It is insoluble in caustic alkalies and mineral acids, excepting *aqua regia.* Its use is extensive as the pigment vermilion.

Mercurous sulphide, Hg_2S, is prepared by passing sulphuretted hydrogen into a mercurous nitrate. The process forms a black precipitate decomposed by heat into mercuric sulphide and mercury.

Ammoniacal mercury compounds: By the action of ammonia and its salts upon salts of mercury, a great variety of substances is formed. They may be regarded as salts of mercurammoniums—that is, of ammonium molecules in which the hydrogen atoms are more or less replaced by mercury according as the compound is formed from a mercurous or mercuric salt.

Tests for mercury compounds: (1) All mercury salts are volatilized or decomposed at the temperature of ignition;

(2) *Copper* precipitates mercury from solutions;

(3) *Stannous chloride* forms a precipitate;

(4) *Hydrogen sulphide* and *ammonium sulphide* produces black precipitates, insoluble in *ammonium sulphide;*

(5) *Potassium iodide* yields a bright scarlet precipitate with mercuric salts, and a green precipitate with mercurous salts;

(6) *Charcoal* and *sodium carbonate* yield metallic mercury.

Mercury—uses: (1) Metallic mercury is used in the construction of barometers, thermometers, and other physical apparatus;

(2) To extract gold and silver from their ores by forming their amalgams;

(3) With tin it forms an amalgam for silvering glass-mirrors, and with silver and gold an amalgam for filling teeth.

VI. METALS OF THE YTTRIUM GROUP.

This group includes a considerable number of metals occurring in gadolinite, cerite, samarskite, and other rare minerals. The extraction and separation of the oxides of these metals are complex and difficult, and the number of distinct oxides or earths thus obtained is not exactly known. The existence of some of these metals is still a matter of dispute. The ten following may be considered established:

	Symbol.	Atomic weight.		Symbol.	Atomic weight.
Scandium	Sc	44;	Samarium	Sm	150;
Yttrium	Y	89;	Terbium	Tb	149;
Lanthanum	La	138;	Decipium	Dp	159;
Cerium	Ce	141.6;	Erbium	Er	169;
Didymium	D	145.4;	Ytterbium	Yb	173.

These rare metals have only theoretical importance. The existence of scandium was predicted by Mendelejeff in advance of its actual discovery in nature. **Cerium oxalate** has a limited used in medicine.

VII. METALS OF THE ALUMINIUM GROUP.

Aluminium, indium, gallium: These metals are trivalent, forming compounds of the forms MCl_3, M_2O_3, etc.

Their oxides are weak bases and their sulphates unite with those of the alkali metals, forming double salts called "alums," which crystallize in regular forms of the isometric system.

ALUMINIUM. Symbol Al. Atomic weight 27.3.

Occurrence: As a *silicate*, it enters into the composition of all primitive rocks, of feldspars, slates, and clays; of the minerals, *garnet*, *emerald*, *topaz*. As an *oxide*, Al_2O_3, it is the mineral corundum, which in its varying degrees of coloring and purity is the *ruby*, *sapphire*, *Oriental topaz*, Oriental amethyst, and Oriental emerald. An impure variety is called emery. As a *phosphate*, it occurs as turquoise. As a *fluoride*, it occurs as cryolite, $Al_2F_6,6NaF$. As an *aluminate*, with iron, *bauxite*, a hydrated aluminate of iron. It is also a constituent of other less important minerals.

Preparation: (1) By decomposing aluminium chloride by metallic potassium (Wöhler's original method).

(2) By decomposing the double chloride of sodium and aluminium, $AlF_3,3NaF$, by metallic sodium (Deville's process).

Both of these original processes have been supplanted by the modern electric methods:

(3) The electrolytic reduction of oxide of aluminium having a cover of fused cryolite, producing metallic aluminium (Heroult and Hall's process); and

(4) The electrolytic reduction of corundum, Al_2O_3, with copper, producing an alloy of copper and aluminium (Cowle's process).

Properties and uses: Aluminium is a tin-white metal, brilliant and capable of being highly polished; specific gravity 2.6 to 2.74; malleable and ductile; an excellent conductor of heat and electricity. It does not readily tarnish in air; is easily worked, and combines the properties of lightness and strength to an extraordinary degree. Its specific heat is very high, 0.2253, being double that of iron. Its melting-point is

625° C. It imparts great strength to its alloys. It is trivalent; forms only one class of compounds. As a metal it is used in the manufacture of delicate apparatus and ornamental objects. As an alloy with copper, called aluminium bronze, and with steel it is coming into constantly increasing use.

Aluminium chloride, $AlCl_2$, is produced by: (1) Aluminium hydrate in hydrochloric acid (in solution);

(2) Alumina, finely divided carbon, and chlorine gas:

$$Al_2O_3 + C_3 + Cl_6 = 2AlCl_3 + 3CO$$

(an anhydrous solid).

Aluminium and sodium chloride, $AlCl_3,NaCl$, is a double salt obtained by melting together the proper proportions of the two chlorides.

Aluminium fluoride, AlF_3, is prepared by the action of gaseous silicon fluoride on alumina. Its cubic crystals, volatilizing at a red heat, are insoluble in water and resist the action of acids.

Aluminium and sodium fluoride, $AlF_3,3NaF$, is found in nature as cryolite at Evigtok, Greenland.

It is **prepared** from hydrofluoric acid and a mixture of calcined alumina and sodium carbonate. Its natural crystals, softer than feldspar, are used in the preparation of aluminium; for the manufacture of soda-ash; for aluminium sulphate, and in the production of glass resembling porcelain.

Aluminium oxide, Al_2O_3, or alumina, occurs as the mineral corundum. It may be prepared from aluminium sulphate and an excess of ammonia hydrate. The bulky, white, gelatinous precipitate of aluminium hydrate thus obtained is converted into an oxide by ignition. The oxide is a white, tasteless, coherent mass, and little affected by acids, but fusible before the oxyhydrogen blowpipe. It acts as a weak base.

Hydrates of aluminium: The *monohydrate* occurs native as diasphore. The *trihydrate* occurs native as gibbsite. It has a powerful attraction for organic matter and precipitates solutions of vegetable coloring-matters, forming pigments called "*lakes.*" The fibre of cotton impregnated with alumina acquires the power of retaining coloring-matters, hence the great use of aluminous salts as *mordants* to produce fast colors.

The hydrogen in aluminium trihydrate may be replaced by an equivalent quantity of various metals. Such compounds are called "*aluminates,*" two of them occurring as minerals, spinel an aluminate of magnesium, Al_2MgO_4; and gahnite an aluminate of zinc, Al_2ZnO_4.

Aluminium sulphide, Al_2S_3, is obtained when vapor of carbon disulphide is passed over alumina at red heat. This sulphide is instantly decomposed by water, with the evolution of sulphuretted hydrogen.

Aluminium sulphate, $Al_2(SO_4)_3,18H_2O$, is formed:

(1) From aluminium hydrate and dilute solution of sulphuric acid, then evaporating;

(2) On a large scale by treating clay with sulphuric acid.

Properties: Its thin pearly plates, soluble in 2 parts of water, have a sweet astringent taste and acid reaction. At a red heat it is decomposed. It combines with the sulphates of potassium, sodium, ammonium, and the other alkali metals, forming double salts of great importance.

Common alum, the source of all the preparations of alumina, is $AlK(SO_4)_2,12H_2O$, manufactured from clay. We may replace K by NH_4, Na, Ag, Tl, Cs, Rb; or Al by Cr, Ga, In, Fe, or Mn, and in every case we obtain a salt having 12 molecules of water, crystallizing in regular octahedrons. *Potassium* and *ammonium* alums are both important, and are used as mordants in dyeing and in the preparation of skins, etc.

Phosphates of aluminium: The normal salt, $AlPO_4$ or $Al_2(PO_4)_2$, is prepared from a natural solution of alum with sodium phosphate. It occurs as the mineral navellite, $2Al(PO_4)_2,Al_2(OH)_6 + 9H_2O$, containing small quantities of Cl and F; and as the mineral turquoise, $Al_2(PO_4)_2,Al_2(OH)_6 + 2H_2O$.

The **silicates of aluminium** occur in a great number of crystalline minerals, but most abundantly as feldspar. Granite, porphyry, trachyte, and other ancient unstratified rocks consisting mainly of this mineral, suffer complete decomposition by natural agencies and are converted into a soft friable mass of earthy matter. This is the origin of *clay*.

Feldspar may be separated from quartz and mica in granite by grinding and washing. It is used in the manufacture of porcelain. The composition assigned to unaltered feldspar is:

$$Al_2O_3K_2O,6SiO_2 \text{ or } Al_2K_2Si_6O_{16}.$$

Kaolin: *Pure porcelain clay*, or *kaolin*, is a hydrous aluminium silicate, $H_2Al_2Si_2O_8 + H_2O$, derived from feldspar rocks by atmospheric processes called weathering. *Fire-clays* contain large admixtures of silica.

Clays containing calcium carbonate are called *marls*.

Clays are called "*acid*" or "*basic*" according to the excess of SiO_2 or Al_2O_3 in their composition.

The plasticity of clay is due to the chemically combined water, and is rendered less dependent on the amount of alumina, calcium, and magnesium present by heating to high temperature, as the combined water is thus expelled and the clay loses its plasticity and becomes hard and porous.

Tests for aluminium compounds: (1) With *cobaltic nitrate* heated before the blowpipe they give an infusible mass of characteristic blue color;

(2) *Caustic potash* or *soda* gives a bulky gelatinous precipitate of aluminium hydrate freely soluble in an excess of the alkali;

(3) *Ammonia* produces a similar precipitate insoluble in an excess of the reagent;

(4) The *alkaline carbonates* and *ammonium carbonate* give precipitates of the hydrate, liberating carbon dioxide gas.

The manufacture of porcelain: Clays, being plastic, are easily moulded and lose their plasticity by heat, becoming hard and porous. In making porcelain the finely powdered kaolin is mixed with water to a thick paste and moulded by a potter's wheel or in moulds. A little feldspar, chalk, or gypsum is added, in order to form a fusible silicate, in quantity just sufficient to bind the particles more together; and to diminish the contraction which clay undergoes in the fire a quantity of finely divided silica is added. Upon firing, as this process of burning is called, a porous "biscuit-ware" is obtained, which is afterward subjected to a glazing process.

The glazing material is generally powdered feldspar mixed to a very thin paste with water. The porcus biscuit is dipped into this mixture and withdrawn, and the water permeates the piece, leaving the powder evenly spread upon the surface. It is once more dried and fired at a high temperature. The feldspar, being fusible, melts to a thin, smooth, glassy layer. The ornamentation in gilt and enamel is afterward applied, the colors used consisting of various metallic oxides: cobalt oxide for blue, chrome oxide for green, etc. Some colors are put on previous to glazing, but the more delicate tints are imparted in a separate firing over the glaze.

The manufacture of stoneware: Coarse kinds of porcelain are made from impure clays containing oxide of iron and a little lime, to which it owes its partial fusibility. Many recipes are used to impart glaze to stoneware, the simplest being the throwing of common salt into the heated furnace. The salt volatilizes and is decomposed by the silica of the ware and the vapor of water always present. It forms a fusible silicate of sodium, which spreads over the surface of the ware, giving a thin but excellent glaze.

The manufacture of earthenware: The finest kind is made from a white secondary clay mixed with a considerable quantity of silica. The articles are dried, fired, and dipped into a readily fusible glaze mixture, sometimes containing oxide of lead, then dried and reheated to form a glaze. The ornamental designs in blue and other colors so common on plates and household articles are printed on paper with the enamel pigment mixed with oil and transferred while wet to the unglazed ware. When dry the articles are glazed. The coarser kinds of earthenware are sometimes covered with a whitish, opaque glaze containing oxides of lead and tin. Such a glaze is liable to be attacked by acids, and is dangerous for culinary purposes.

INDIUM. Symbol In. Atomic weight 114.4.

Indium *occurs* in a few zinc ores, and is found in the flue-dust of zinc furnaces. It is *obtained* from the metallic sponge of zinc-works. It was discovered by Reich and Ruhter in 1863.

Properties: When reduced from its oxide by metallic sodium it is silver-white, soft, and ductile. When heated to redness in air, it burns with a violet flame, yielding yellow sesquioxide. It is a trivalent element, soluble in strong mineral acids, and is precipitated from solutions by *zinc* and *cadmium.* The spectrum of indium has two indigo-colored lines. It was the observation of this peculiar spectrum that led to the discovery of the metal.

The formulæ of the principal normal **indium compounds** are as follows:

Chloride,	$InCl_3$;
Indium and ammonium chloride,	$2NH_4Cl,InCl_3 + H_2O$;
Oxide, yellow,	In_2O_3 ;
Hydroxide,	$In(OH)_3$;
Nitrate,	$In(NO_3)_3$;
Sulphate,	$In_2(SO_4)_3 + 9H_2O$.

The sulphate forms an *alum.*

GALLIUM. Symbol Ga. Atomic weight 69.8.

Gallium *occurs* in a few zinc blendes, and is *obtained* by electrolysis from a solution of its oxide in potash or ammonia.

Properties: It is a hard, white, ductile metal, somewhat malleable, and acquiring a good polish by pressure. Specific gravity 5.9. It melts at 30.1° C., hence liquefies when pressed between the fingers. The melted metal adheres to glass, giving a mirror whiter than mercury. It oxidizes when heated to redness, but does not volatilize. Its bright electric spectrum, showing a brilliant line and a fainter band in the violet, caused its discovery. The existence of a metal having the atomic weight and properties of gallium was predicted, as already mentioned, by Mendelejeff. Its oxide is GaO_3; its sulphate forms an alum, and its chloride is $GaCl_3$ or Ga_2Cl_6.

VIII. METALS OF THE IRON GROUP.

Manganese,	Cobalt,
Iron,	Nickel.

Characteristics: These metals form basic oxides, as MO, in which they are bivalent, and corresponding sulphates, which unite with the sulphates of the alkali metals, forming double sulphates, isomorphous with those of the magnesium group—*e. g.*, $K_2Fe(SO_4)_2 + 6H_2O$. Manganese and iron also form sesquioxides, which, like alumina, act as weak bases, and their sulphates, like aluminium sulphate, unite with the sulphates of the alkali metals, forming alums isomorphous with common alum—*e. g.*, *potassio-ferric sulphate*, $KFe^{iii}(SO_4)_2 + 12H_2O$ or $K_2(Fe_2)^{vi}(SO_4)_4 + 24H_2O$. The sesquioxides of nickel and cobalt, on the other hand, act as peroxides dissolving in acids with the evolution of hydrogen or chlorine. Manganese and iron likewise form salts, which may be supposed to contain the trioxides, MO_3, or in which the metal is sexivalent, therefore analogous to the sulphides in composition—*e. g.*, *potassium ferrate*, K_2FeO_4 or K_2O,FeO_3. Lastly, manganese forms a class of salts, the *permanganates*, $KMnO_4$ or $K_2OMn_2O_7$, analogous in composition to the perchlorates, and isomorphous therewith. In these salts the manganese, like chlorine in perchlorates, is supposed to be septivalent.

MANGANESE. Symbol Mn. Atomic weight 54.8.

Occurrence: It is tolerably abundant in nature, occurring in many rocks and minerals. Its *chief minerals* are: pyrolusite, MnO_2; manganite, Mn_2O_3,H_2O; braunite, Mn_2O_3; hausmannite, Mn_3O_4; rhodochrosite, $MnCO_3$. It is widely diffused in small amounts through many minerals, in soil, and in the ashes of some plants.

Preparation and properties: It is prepared from the carbonate or oxide by reduction. It is reddish in color, very hard and brittle. When powdered it decomposes water even at low temperatures, and is soluble in dilute sulphuric acid with great energy, freeing hydrogen. It oxidizes easily, is slightly magnetic, and fusible with difficulty.

The **chlorides of manganese** are the dichloride, $MnCl_2,4H_2O$; and the trichloride, Mn_2Cl_6.

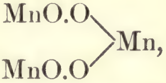
Oxides of manganese: (1) *Monoxide* or *manganous oxide*, MnO;

(2) *Trimangano-tetroxide* or *manganoso-manganic oxide*, Mn_3O_4;

(3) *Sesquioxide* or *manganic oxide*, Mn_2O_3;

(4) *Dioxide* or *peroxide*, MnO_2.

The first is a strong, the third a weak base, the second and fourth are neutral. There are also several oxides intermediate between the monoxide and the dioxide occurring as minerals. Manganese forms two series of oxygen salts, *manganates* and *permanganates*. Their corresponding oxides, MnO_3 and Mn_2O_7, are not known.

Mn_3O_4, probably MnO,Mn_2O_3,  $\left.\begin{matrix}MnO.O\\MnO.O\end{matrix}\right\rangle Mn$, **trimangano-tetroxide**, or *red oxide of manganese*, occurs in the mineral hausmannite. It is prepared by heating the di- or sesquioxide to whiteness. It is a reddish-brown substance which does not form salts soluble in acids.

The **peroxide, MnO_2**, occurs as the mineral pyrolusite. It is prepared by calcining the nitrate, and is a black substance insoluble in water, but uniting with stronger bases, as potash, lime, etc., to form *manganates*—*e. g.*, $CaOMnO_2$ or $CaMnO_3$. Great quantities are used in the manufacture of bleaching-powder, oxygen, salts of manganese, and in the manufacture of steel.

Manganese sulphate, $MnSO_4,7H_2O$, is derived from a solution of the monoxide in sulphuric acid. It is a beautiful rose-colored salt, very soluble, forming a double salt with potassium sulphate. It is used to produce a permanent brown dye.

Potassium manganate: The oxide of manganese fused with potash becomes K_2MnO_4, potassium manganate, of a deep green color, very soluble in water, from which green crystals are obtained. In these salts manganese, like chromium in chromates, is sexivalent.

Potassium permanganate is obtained:

(1) By decomposition of potassium manganate in water, forming $K_2Mn_2O_8$ or $K_2O_7Mn_2O_7$:

$$3K_2MnO_4 + 2H_2O = MnO_2 + K_2Mn_2O_8 + 4KHO.$$

(2) It is commercially prepared from manganese dioxide, potassium chlorate, and potassium hydroxide.

The dark purple crystals thus formed are soluble in water and decomposed by contact with organic matter. It is used to test for the presence of organic matter, as a disinfectant, and as a reagent for determining iron in the laboratory. The green and red disinfectants known as *Condy's fluids* are alkaline manganates and permanganates.

Permanganic acid, $H_2Mn_2O_8$, results from distilling potassium permanganate with sulphuric acid. The violet vapors, condensing to a green-black fluid with metallic lustre, form the acid. It is a most powerful oxidizing agent, instantly setting fire to paper and alcohol.

Tests for manganese compounds: (1) The *fixed caustic alkalies* and *ammonia* give white precipitates insoluble in an excess, quickly becoming brown.

(2) *Carbonates of fixed alkalies* and of *ammonia* give white precipitates insoluble in an excess of ammonium carbonate.

(3) *Hydrogen sulphide* has no effect; *ammonium sulphide* gives an insoluble flesh-colored sulphide of manganese.

(4) *Potassium ferro-cyanide* gives a white precipitate.

(5) They are easily detected by the blowpipe. The hot bead of a manganese salt touched to a crystal of sodium nitrate gives amethyst-colored froth, a very delicate test. Also heated on platinum foil with sodium carbonate, it yields a green mass of sodium manganate.

Uses of manganese: Two important alloys of manganese and iron are used extensively in the manufacture of steel—viz., spiegeleisen, which is cast-iron containing from 10 to 20 per cent. of manganese, and ferro-manganese, which is iron containing from 60 to 80 per cent. of manganese. The black oxide is an important agent in the production of chlorine, the preparation of green and red disinfecting manganates, purple glass, and black glazes for earthenware.

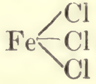
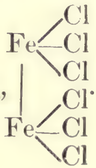
IRON (FERRUM). Symbol **Fe.** Atomic weight 56.

Occurrence : Iron, the most important metal, occurs rarely as a mineral. With nickel it is found in all meteorites. As an *oxide* it is of universal presence. The principal oxide ores are magnetite, Fe_3O_4; hematite, Fe_2O_3; limonite, $Fe_2O_3,3H_2O$. It constitutes a great part of the coloring-matter of rocks and soils, and is contained in plants. It is an essential component of animal blood and of the water of many springs, etc. As a *sulphide* it occurs in the minerals pyrite, FeS_2, and pyrrhotite, Fe_8S_9, and in combination with other sulphides. As a *carbonate* it is found in the mineral siderite, $FeCO_3$, one of the most important ores of iron.

Preparation : Pure iron may be prepared in a crucible by fusing 4 parts of fine iron-wire and 1 part of black iron oxide with a cover of flux. The traces of carbon and silicon present in the wire are oxidized by the oxygen of the oxide.

Properties : *Pure iron* has a white color and a perfect lustre. Specific gravity 7.8. It is extremely soft and tough, and the most tenacious of all metals: a wire $\frac{1}{36}$ of an inch in diameter will bear a weight of 60 pounds. The crystalline form is probably the cube. Fusing with difficulty under heat, before becoming liquid it passes into an intermediate pasty state; pieces of iron in this pasty state can be hammered or pressed, called *welding*, into a single mass. Usually a little sand is sprinkled over the heated surfaces, to combine with the superficial surface of oxide, forming a fusible silicate, which is subsequently forced out from between the pieces of iron by the pressure applied. It does not oxidize in dry air. Heated to redness, it becomes coated with a scale of black oxide; at high white heat it burns brilliantly, forming an oxide. Its combustion in oxygen gas occurs with great ease. The finely divided spongy metal, prepared by reducing the red oxide with hydrogen, takes fire spontaneously in air. Pure water, free from air and carbonic acid, does not tarnish polished iron; but the combined agency of free oxygen and moisture speedily produces rust, which is the hydrated oxide of iron.

At a red heat iron *decomposes water*, yielding hydrogen and the black oxide of iron. Iron is freely soluble in dilute sulphuric and hydrochloric acids with the separation of hydrogen. Iron is strongly magnetic up to red heat, at which temperature it loses this property.

It forms two classes of **compounds**, the *ferrous* compounds, acting as bivalent, FeO, $FeCl_2$, $FeSO_4$; and *ferric* compounds, in which, like aluminium, it may be regarded as either triad or tetrad. Ferric chloride may be regarded as $FeCl_3$,  ; or as Fe_2Cl_6,  The vapor density of this compound, determined by Deville, favors the latter formula.

All **commercial iron** contains impurities, mainly carbon, with smaller amounts of silicon, manganese, and still smaller amounts of phosphorus and sulphur, Its properties are remarkably affected, according to the proportions of these impurities. It is roughly *classified* as follows: Wrought-iron, or malleable iron, contains less than ½ per cent. of these impurities; cast- or pig-iron contains from 2½ to 6 per cent.; steel lies intermediate between these two.

Iron appears in commerce in three forms, as cast-iron, wrought-iron, and steel.

Cast-iron is produced in the *blast furnace*. Internally the furnace shape is like two hollow cones placed base to base, sometimes separated by a hollow cylinder. Air is blown in at the bottom through water-cooled apertures, called "twyeres," and the gases produced (containing about 20 per cent. carbon monoxide) are drawn off from the top and utilized to heat the blast from 1400° to 1600° F.

The interior of the furnace is lined with fire-brick. The exterior consists of sheet-iron suitably braced and supported. Alternate layers of flux, limestone, ore, and fuel are fed at the top and descend through the furnace. The upper portion of the furnace is called the *zone of preparation,* and in it moisture, bituminous matter, and carbon dioxide are driven off. Below this is the *zone of reduction,* and it is here that the oxides of iron are reduced to metallic iron by the carbon monoxide gas and incandescent carbon of the fuel. At the lower portion of this zone the spongy iron produced absorbs some carbon from the fuel and becomes more fusible. This portion of the furnace is called the *zone of fusion,* as it is here that the solid reduced iron is converted to liquid iron (with assimilated carbon from fuel). In addition to this the flux (calcite or dolomite) unites with the infusible siliceous elements of the ore, yielding a fusible silicate called "slag." This slag, together with the reduced and carburized iron, falls to the bottom of the crucible, the lighter slag floating on the cast-iron protecting it from the blast. From the beginning of the fusion zone the iron, in contact with the fuel, takes to itself the metalloids, carbon and silicon, in quantity depending on the temperature and length of time they are in contact, hence the variation of impurities, from 2 to 6 per cent. of carbon.

When sufficient iron has accumulated it is drawn off from the crucible hearth and either cast into sand-moulds, called "pigs," or into a ladle, to be used direct in Bessemer's process for making steel. The air blown in through the twyeres meets incandescent carbon and immediately forms carbon dioxide, yielding great heat (it is just above the twyeres that the hottest part of the furnace exists, about 4000° F.). The carbon dioxide produced is immediately converted to carbon monoxide, $CO : CO_2 + C = 2CO$, with absorption of heat. The action of the CO as a reducing-agent is:

$$Fe_xO_y + yCO = Fe_x + yCO_2.$$

This CO_2 is reconverted by the C of the fuel into 2CO, etc. The gases drawn off from the furnace top consist of about 60 per cent. nitrogen, the remainder, 40 per cent., consisting variously of CO and CO_2, with a little moisture and ammonia compounds, etc.

The varieties of *pig-iron* are roughly graded as *gray*, *white*, and *mottled*, always crystalline in structure and more or less brittle.

White iron is hard, highly crystalline, and quite brilliant. Its carbon contents are chiefly in a state of combination.

Gray iron is softer, closer-grained, and has its carbon partly in combination and partly as graphite.

Mottled iron is a mechanical mixture of the two.

Spiegeleisen is a particularly brilliant and crystalline pig-iron having about 6 per cent. carbon and up to 20 per cent. of manganese. It is used in steel manufacture. The common impurities of cast-iron are silicon, sulphur, and phosphorus, the last two elements being particularly objectionable. The sulphur renders the metal "*red-short*" or "*hot-short*," or brittle at a red temperature; while phosphorus renders it "*cold-short*" or brittle when cold.

Gray iron is used for foundry purposes and for the manufacture of steel, especially by Bessemer's process. *White iron* is used for forge purposes, for the manufacture of wrought-iron by puddling, and in the manufacture of steel.

Wrought-iron is sometimes prepared by directly heating the iron ore with charcoal in a furnace and purifying the pasty product from adhering slag and fuel by hammering or squeezing, known as "blooming." Another method is to refine cast-iron in refiners or puddling furnaces. The impurities—carbon, silica, manganese, and phosphorus—are removed by heating the mass with oxides of iron. The carbon becomes carbon dioxide, and the other impurities are removed in the slag. The iron becomes pasty, and is rolled into bars. The process is technically called "puddling."

Wrought-iron is tough, fibrous in structure, and almost infusible. At a red heat it can be worked and welded by hammering or rolling, whence its great value as a construction material.

Steel may be made in several ways:

(1) *Cement steel* is made by carbonizing malleable iron. This is accomplished in furnaces enclosing rectangular boxes of siliceous material containing bars of wrought-iron packed in charcoal. Steel thus produced, called "blister steel," is made homogeneous by melting it in crucibles, after which it is cast into small ingots. The cementation process is also used for hardening the surface of armor plates.

(2) *Crucible steel* is a crucible-melted mixture of irons of varying carbon-contents, with or without carbonizing or decarbonizing materials, according to the product desired.

The high-grade carbon steels are used for tools, firearms, springs, etc The special grade steels are employed as chrome steel, tungsten steel, and manganese or Franklinite steel, etc.

(3) *Open-hearth steel,* acid process: By melting pig-iron and ore, known as "pig-and-ore," or Siemens's process; or by melting pig-iron and scrap-iron and steel, known as Siemens-Martin's process, on the hearths of a reverberatory furnace. When the impurities—silicon, manganese, and carbon—are oxidized and removed the residue is carbonized to the desired extent by the addition of suitable recarbonizers—viz., spiegeleisen, ferro-manganese—or by filtering the decarbonized mass of melted metal over carbon filters, by which carbon in required quantity is taken up. These low-carbon steels are especially suited for armor-plate, fire-boxes, tanks, tires, and construction material.

(4) *Bessemer steel,* acid process: This method decarburizes molten gray iron by means of blasts of air. The molten iron is contained in a "converter" of wrought-iron lined with brick, having twyere holes at the bottom, revolving on horizontal trunions, one of which is hollow and conveys the blast. The capacity of this vessel is 15 tons or greater. The molten pig, either direct from the blast-furnace or remelted in a "cupola" furnace, is run into the "converter," which is halfway turned down. As the "converter" is turned up it automatically opens the air-valve and the air is driven through the melted metal, oxidizing the impurities, silicon, manganese, and carbon. The heat necessary for the process is furnished by the oxidation of impurities, carbon, silicon, and manganese. The operation is guided by the appearance of the flame. When the molten metal is free from impurities the converter is turned down, and the metal recarbonized as before by the addition of spiegeleisen, ferro-manganese, or carbon-filters. It is then cast into ingots, to be converted into the final product. This steel is especially adapted to the manufacture of rails and construction material.

In these processes the steel produced contains all the phosphorus of the ore. This phosphorus can only be eliminated from the molten metal by means of a basic slag, the presence of which in an acid-furnace would rapidly combine with the furnace-lining, forming a fusible slag and destroying the furnace. The basic open-hearth and the basic Bessemer processes are essentially the acid processes conducted in furnaces or converters having basic linings. The steels thus produced are called respectively basic open-hearth and basic Bessemer steel. Phosphorus, the most objectionable impurity in iron, is removed by the basic slag, which can only be used in furnaces having a basic lining.

Ferrous chloride, $FeCl_2$, is procured by dissolving iron in hydrochloric acid. The solution, concentrated and evaporated, yields green crystals of $FeCl_2,4H_2O$, which are very soluble, deliquescent, oxidizing rapidly in air. It is used in metallurgy.

Ferric chloride, Fe_2Cl_6, is obtained by dissolving ferric oxide in hydrochloric acid. By concentration and evaporation the solution yields red crystals—hydrated—very soluble in water and alcohol. It forms double salts with potassium and ammonium chlorides, and is used as a reagent in the laboratory and as a material to stop bleeding.

Ferrous iodide, FeI_2, is obtained by digesting iodine with water and metallic iron. The solution is pale green, and yields crystals resembling the chloride. It rapidly oxidizes in contact with air. Medicinally it is important.

Ferric iodide, Fe_2I_6, is yellowish-red and soluble.

The **oxides of iron** are:

(1) *Ferrous oxide,* FeO;

(2) *Ferric oxide,* Fe_2O_3;

(3) *Triferro-tetroxide,* $Fe_3O_4(FeO,Fe_2O_3)$;

(4) *Trioxide,* supposed to exist in ferrates, but not isolated, FeO_3.

Ferrous oxide, FeO, or monoxide, isomorphous with magnesia, zinc oxide, etc., is a powerful base neutralizing acids.

Ferric oxide, Fe_2O_3, or sesquioxide, occurring extensively as the minerals hematite, Fe_2O_3, and limonite, $Fe_2O_3,3H_2O$, is prepared:

(1) By calcining ferrous sulphate;

(2) By precipitating ferrous chloride or sulphate with an excess of ammonia, washing, drying, and igniting. The yellow-brown hydrate produced is a fine powder having a red color. Unaltered by fire, it is easily reduced at high temperatures by carbon or hydrogen. It forms with acids a series of reddish salts of acid reaction and astringent taste. It is not acted upon by the magnet.

Uses: As an ore of iron it is important. It is the pigment known as Venetian red. It is used as a polishing material for glass and precious metals; as jewellers' rouge and crocus powder. The *hydrated oxide*, $Fe_2O_3,3H_2O$ or $Fe_2(OH)_6$, is used for purifying coal-gas, and as an *antidote* for *arsenical poisoning.*

Triferro-tetroxide, Fe_3O_4, ferroso-ferric oxide, also called *magnetic oxide* and *lodestone,* is one of the most valuable of the iron ores, occurring as the mineral magnetite, *lodestone* itself being a magnet. It is precipitated from a properly proportioned mixture of ferrous and ferric salts by an excess of alkali, and boiling the mixed hydroxides. A black sandy substance, consisting of minute crystals of magnetic oxide, is thus obtained.

The ferrates:

Potassium ferrate, K_2FeO_4 or K_2O,FeO_3;
Barium ferrate. $BaFeO_4$ or BaO,FeO_3.

Neither the **acid, H_2FeO_4,** nor **oxide, FeO_3,** is known in a separate state.

Ferrous sulphate, $FeSO_4$, *green vitriol, iron vitriol,* or *copperas,* occurs as the mineral melanterite, but is prepared commercially by the contact of air and moisture with iron pyrites. The salt produced is dissolved out by water, and the solution crystallized. It is obtained in large quantities as a by-product in galvanizing iron. The "pickle" for cleansing the iron previous to its being coated with zinc is dilute sulphuric acid. This acid, gradually becoming saturated with iron, yields crystals of iron sulphate. It is also a by-product in copper and silver works. It generally crystallizes with $7H_2O$, sometimes with 4 or $2H_2O$. It is green in color, efflorescent, and soluble in 2 parts of cold water. It forms double salts with potassium and ammonium sulphates. With tannin or a solution of galls it yields a deep black color. It is used in the manufacture of writing-inks and as a disinfectant.

Ferric sulphate, $Fe_2(SO_4)_3$ or $Fe_2O_3,3SO_3$, occurs in several minerals as a basic sulphate. It forms alums with potassium and ammonium :

$$Fe^{iii}K(SO_4)_2,12H_2O.$$

Ferrous nitrate, $Fe(NO_3)_2$, and **ferric nitrate, $Fe_2(NO_3)_6$,** are used in dyeing.

Ferrous carbonate, $FeCO_3$, occurs as the mineral siderite, an important ore of iron known as *spathose iron ore, iron spar, clay-iron stone.* It is often found in mineral waters, being soluble in an excess of carbonic acid.

It is prepared from a ferrous salt and an alkaline carbonate, making a white precipitate which cannot be washed and dried without absorbing oxygen and losing carbonic acid.

The **phosphates** of iron are all insoluble.

Several compounds of sulphur and iron are known. The most important are :

Monosulphide, FeS ; Bisulphide, FeS_2 :

Ferrous sulphide, FeS, or monosulphide, is produced by heating iron and sulphur. It is black, brittle, magnetic, and soluble in dilute acids, yielding sulphuretted hydrogen gas.

Ferric sulphide, FeS_2, or bisulphide, occurs as the minerals pyrite and marcasite. The brass-yellow colored crystals of pyrite, formerly called *fool's gold*, are not attracted by the magnet. They are hard and insoluble in dilute acids. Pyrite is one of the chief materials for manufacturing sulphuric acid. The magnetic sulphide of iron, Fe_7S_8, occurs as the mineral pyrrhotite.

Compounds with **carbon, phosphorus,** and **silicon** exist, but little is known respecting them in a definite state. The carbonide is contained in cast-iron and steel, communicating ready fusibility. The compound with silicon also occurs in cast-iron.

Tests for iron compounds: FERROUS SALTS are distinguished as follows:

(1) *Caustic alkalies* and *ammonia* give nearly white precipitates insoluble in an excess of the reagent, rapidly becoming green and ultimately brown by exposure to air;

(2) *Carbonates of potassium, sodium,* and *ammonium* give precipitates of white ferrous carbonate, also subject to change in color;

(3) *Hydrogen sulphide* gives no precipitate;

(4) *Ammonium sulphide* yields black ferrous sulphide, soluble in dilute acids;

(5) *Potassium ferrocyanide* yields a white precipitate becoming deep blue by exposure to air.

The *ferricyanide* gives at once a deep blue precipitate.

FERRIC SALTS are distinguished as follows:

(1) *Caustic fixed alkalies* and *ammonia* give foxy-red precipitates of hydroxide, insoluble in an excess;

(2) The *carbonates* behave in a similar manner;

(3) *Hydrogen sulphide* gives a nearly white precipitate of sulphur and reduces the ferric oxide to ferrous;

(4) *Ammonium sulphide* gives a black precipitate slightly soluble in an excess;

(5) *Potassium ferrocyanide* yields Prussian blue;

(6) *Tincture* or *infusion of gall-nuts* gives a bluish-black color with the most dilute solution of ferric salts;

(7) *Sulphocyanide of ammonium* gives a blood-red precipitate with the most dilute solution.

All compounds of iron heated on charcoal with sodium carbonate yield a magnetic mass.

COBALT. Symbol Co. Atomic weight 58.3.

Occurrence: Cobalt is comparatively a rare metal. It occurs as sulphides, arsenides, arsenates, etc. Its minerals are linnæite, Co_3S_4; smaltite, $(CoFeNi)As_2$; cobaltite, $CoS_2 + CoAs_2$; erythrite, $Co_3As_2O_8 + 8H_3O$. It is generally present in meteorites.

Properties: Cobalt is a reddish-white, brittle, tenacious solid having a high melting-point. It is unchanged by air and but feebly attacked by dilute acids. It is strongly magnetic, and forms two classes of salts, cobaltous and cobaltic, the latter class being very unstable.

Cobaltous chloride, $CoCl_2$, dichloride of cobalt, prepared from the oxide and hydrochloric acid, forms a deep rose-red solution, depositing hydrated crystals of the same color. These are transformed by heat to anhydrous blue crystals, which in contact with water dissolve to a red liquid.

A dilute solution is used as *blue sympathetic ink*. Characters written on paper are invisible from paleness of color until the salt has been rendered anhydrous by heat, when the letters appear blue. On laying the paper aside moisture is absorbed and the writing disappears. Green sympathetic ink is a mixture of the chlorides of cobalt and nickel.

Oxides of cobalt: **CoO**, monoxide of cobalt, cobaltous oxide; **Co_2O_3**, sesquioxide, cobaltic oxide; **Co_3O_4**, cobaltoso-cobaltic oxide.

Cobaltic oxide is a weak base soluble in acids, forming brown solutions easily decomposed. The most stable salt is the acetate. With potassium and ammonium it forms double salts which are more stable.

Tests for cobalt compounds: COBALTOUS SALTS:

(1) *Potassium hydroxide* gives a blue precipitate turning red.

(2) *Ammonia* gives a blue precipitate turning brown.

(3) *Sodium carbonate* yields a pink precipitate.

(4) *Potassium ferrocyanide* gives a grayish-green precipitate.

(5) *Potassium cyanide* gives a yellow-brown precipitate soluble in an excess.

(6) *Ammonium sulphide* yields a black precipitate insoluble in hydrochloric acid.

COBALTIC SALTS:

(1) *Potassium hydroxide* forms a dark-brown precipitate.

(2) *Ammonia* gives a brownish-red solution.

(3) *Fixed alkaline carbonates* yield a green solution.

(4) *Ammonium sulphide* forms a black precipitate.

The blowpipe-test for cobalt compounds is extremely delicate. The smallest amount dissolved in a borax-bead yields a beautiful blue color.

Uses of cobalt: It is extensively used as a pigment for coloring glass and porcelain.

Smalt's blue is the silicate.

Thenard's blue and *cobalt ultramarine* are compounds of cobalt and aluminium salts.

Rinmann's green is the oxides of cobalt and zinc.

A properly proportioned mixture of the oxides of cobalt, manganese, and iron imparts a fine black color to glass.

The soluble salts are used as sympathetic ink and for plating purposes; the articles so treated are sold as superior nickel plate.

NICKEL. Symbol Ni. Atomic weight 58.8.

Occurrence: It is fairly abundant as the minerals millerite, NiS; niccolite, Ni_2As_2; as a silicate with cobalt in smaltite, $(CoFeNi)As_2$; and as annabergite, $Ni_3As_2O_8 + 8H_2O$.

It is also found in all meteorites.

Preparation and properties: It may be obtained:

(1) From its oxalate and charcoal heated to a high degree in a crucible;

(2) By the reduction of its oxide by hydrogen at a high heat.

Nickel is a white malleable solid, specific gravity 8.8, having a high melting-point. It is less oxidizable than iron and but little attacked by dilute acids. It is strongly magnetic.

Nickel chloride, $NiCl_2$, is prepared by dissolving nickel oxide or carbonate in HCl. The green solution deposits green hydrated crystals, turning yellow by heat.

Nickel sulphate, $NiSO_4$, the most important of nickel salts, occurs in prismatic crystals, $NiSO_4,7H_2O$, soluble in three parts of water. It forms beautiful double salts with the sulphates of potassium and ammonium:

$$NiK_2(SO_4)_2,6H_2O \text{ and } Ni(NH_4)_2(SO_4)_2,6H_2O.$$

Nickel also forms an **oxalate**, **carbonate**, etc.

Nickel salts, when hydrated, usually have a beautiful green color; in the anhydrous state they are yellow.

Tests for nickel compounds: (1) *Caustic alkalies* give an apple-green precipitate of the hydroxide insoluble in an excess.

(2) *Ammonia* gives a similar precipitate soluble in an excess, and changing the solution to a purplish-blue.

(3) *Potassium and sodium carbonates* give pale green precipitates.

(4) *Potassium ferricyanide* yields a greenish-white precipitate.

(5) *Potassium cyanide* gives a green precipitate, soluble in an excess, changing from green to an amber-colored solution.

(6) *Ammonium sulphide* yields a black precipitate slightly soluble in an excess, which changes the solution to a dark-brown color.

Uses of nickel: (1) *Nickel-plating.* The salt employed is the double sulphate of nickel and ammonium, which may be deposited on iron, steel, copper, brass, and other metals.

(2) *Alloys: Coins,* nickel with copper or zinc; *German silver,* nickel with copper and zinc. Other alloys are made for special purposes by varying the proportions and the addition of small amounts of other metals.

IX. METALS OF THE CHROMIUM GROUP.

Chromium,	Tungsten,
Molybdenum,	Uranium.

Characteristics: These metals are hexads, their highest oxides, which are of acid character, having the composition MO_3. They also form lower oxides, MO_2, M_2O_3, M_3O_4, and MO, more or less basic and analogous in composition to the basic oxides of manganese, iron, cobalt, and nickel. Chromium, molybdenum, and tungsten form hexfluorides analogous to the highest oxides, and uranium forms an oxychloride, UO_2Cl_2. As metals they have very little importance; their compounds, however, are very useful.

CHROMIUM (*chroma*, color). Atomic weight 52.4. Symbol **Cr**.

Occurrence: It is not very abundant. The mineral chromite, $FeCr_2O_4$, which is its chief ore, is its main source. It is obtained by reducing its oxides by heat and carbonaceous matter. Almost infusible and very hard, it is soluble in dilute hydrochloric acid. When crystalline it resists the action of acids, even aqua regia. It imparts hardness to steel.

Chromous chloride, $CrCl_2$, dichloride of chromium, is prepared by the action of hydrogen on trichloride of chromium, and dissolving the residue in water. This process yields a blue solution, which absorbs oxygen from the air with extraordinary energy, and acquires a deep green color, passing into chromium oxychloride. It is one of the most powerful reducing agents known.

Oxides of chromium: CrO, Cr_3O_4, Cr_2O_3, CrO_2, and CrO_3.

CrO, monoxide or chromous oxide, is a powerful base, forming pale-blue salts.

Cr_3O_4, trichromic tetroxide, corresponds to the magnetic oxide of iron, but is not salifiable.

CrO_3, chromium trioxide, is the most important of the oxides. It exists as crimson-red, prismatic crystals, deliquescent and soluble in water, forming chromic acid, H_2CrO_4, from which a great variety of chromates may be derived.

Chromic sulphate, $Cr_2(SO_4)_3$, forms double salts with sulphates of potassium and ammonium, making *alums*. It is used to impart a fine green color to glass and as an enamel. The crystalline sesquioxide is used on the surface of razor straps.

Potassium chromate is **K_2CrO_4** or K_2O,CrO_3.

Potassium dichromate, K_2CrO_4,CrO_3, or pyrochromate, exists as red tabular crystals soluble in ten parts of water. Immense quantities of this salt are used in the arts:

(1) In dyeing and calico-printing;
(2) In the preparation of chrome paints;
(3) As an oxidizing agent in bleaching discolored fats and oils;

(4) For battery use;

(5) In photography.

A gelatine film saturated with this salt is rendered insoluble by action of light. A photograph taken on such a film may be made to stand out in actual relief by dissolving away the unattacked parts, and may then be copied by electroplating or in type-metal, or transferred to lithographic stone. This is the basis of the processes of photographic printing, such as heliotypes, autotypes, photolithographs, etc.

Potassium trichromate is $K_2O,3CrO_3$.

Lead chromate, $PbCrO_4$, is prepared by uniting solutions of lead acetate and potassium pyrochromate, and filtering off the yellow precipitate of *chrome-yellow*. By boiling with potassium hydroxide it is converted into a basic chromate, $PbCrO_4$,-PbO, rivalling vermilion in color, *chrome-red*. A mixture of the two yields *chrome-orange*. It is used as a pigment and dye-stuff.

Tests for chromium compounds: (1) *Ammonium sulphide*, a gray-green precipitate;

(2) *Caustic fixed alkalies*, a precipitate of hydroxide soluble in an excess of alkali;

(3) *Ammonia*, the same, but nearly insoluble;

(4) *Carbonates of potassinm, sodium, and ammonium*, a green precipitate of hydroxide slightly soluble in an excess.

The *chromic* compounds yield with

(5) *Barium salts*, a pale-yellow precipitate; *lead salts*, a bright yellow; *mercurous salts*, a brick-red; and *silver salts*, a crimson color.

(6) The blowpipe-test is the green color imparted to a borax bead in both the oxidizing and the reducing flames.

MOLYBDENUM. Symbol **Mo**. Atomic weight 96.

This rare metal **occurs** in small quantities as molybdenite, MoS_2; and wulfenite, $PbMoO_4$.

It is **prepared** by reducing, at an intense heat, molybdic oxide in a charcoal-lined crucible. It is a brittle, white metal, exceedingly infusible, and oxidizing when heated in the air. Specific gravity 8.6.

It forms **complicated compounds.** Its leading oxide, MoO_3, and molybdic acid, H_2MoO_4, are analogous to corresponding oxides and acids of chromium and sulphur. Its salt, *ammonium molybdate,* is an indispensable reagent in the laboratory for the determination of phosphorus in the exact analyses of iron ores and fertilizers.

TUNGSTEN. Symbol W. Atomic weight 184.

It is rare, but more abundant than molybdenum, occurring as the minerals wolframite, $FeWO_4$; scheelite, $CaWO_4$; and stolzite, $PbWO_4$. It is obtained by reducing the oxide with hydrogen, and is then found to be a white, hard, brittle metal, burning to an oxide when heated in the air.

URANIUM. Symbol U. Atomic weight 239.

Uranium, one of the rarer metals, **occurs** in several minerals, such as uraninite (pitchblende), which is its principal ore. It is obtained by decomposing its chloride with metallic potassium. Uranium is silver-white in color; it does not decompose water, but burns to a green oxide. It unites violently with sulphur and chlorine, and forms two classes of compounds, the uran*ic* and the uran*ous.*

Uranic oxide, UO_3, unites with basic metallic oxides, forming salts called uranates, the most important of which is *sodium uranate,* Na_2UO_4. It is much used for imparting a yellow fluorescent color to glass (canary glass), and as a yellow pigment for glazing porcelain.

Uranic nitrate and **acetate** are useful laboratory reagents.

Uses of uranium salts: (1) In enamel-painting;
(2) In glass-staining;
(3) In photography.

X. METALS OF THE TIN GROUP.

Tin,	Zirconium,
Titanium,	Thorium.

These metals are tetrads, like silicon, forming volatile tetrachlorides; also tetrafluorides, which unite with other metallic fluorides, forming double salts analogous to the silicofluorides in composition and isomorphous with them.

TIN (STANNUM). Symbol **Sn.** Atomic weight 117.8.

Tin, one of the useful metals, **occurs** in a few mineral species. Its ore is cassiterite (tin-stone), SnO_2. Tin is rarely found as a sulphide. It is obtained by the reduction of its oxide by carbon in furnaces:

$$2SnO_2 + 2C = Sn_2 + 2CO_2.$$

Properties: Tin is a white metal, soft, specific gravity 7.3, very malleable, ductile, but not tenacious. At 200° C. it becomes brittle and may be powdered. It melts at 235° C. When bent or twisted, it emits a peculiar crackling noise, called the "cry" of tin, caused by the friction of interlaced crystals. It is but little acted upon by air and water, but oxidizes readily when heated above its melting-point. It is soluble in hydrochloric acid, emitting hydrogen.

It forms two **classes of salts**:

The *stannous* acting as bivalent;
stannic " " quadrivalent.

Stannous chloride, $SnCl_2$ or Sn_2Cl_4, or dichloride, is prepared in the anhydrous state by distilling a mixture of calomel and powdered tin. This chloride is gray, resinous-looking, fusible below redness, and volatile at a high temperature. The *hydrated chloride,* $SnCl_2,2H_2O$, presents needle crystals freely soluble in water. It is employed in solution as a deoxidizing agent, reducing salts of mercury and other metals of the same class. It forms crystallizable double salts with alkali metal chlorides, as $SnCl_2,2KCl$.

Uses: (1) It is used as a reagent;
(2) As a mordant in dyeing and calico-printing;
(3) As an "antichlor."

Stannic chloride, $SnCl_4$, or tetrachloride, may be prepared from:

(1) Chlorine and metallic tin;
(2) By distilling 1 part of tin and 5 parts of mercuric chloride.

It is a thin, colorless, mobile liquid. It boils at 120° C.; fumes in air; and may be solidified by mixing with one-third part of water to a soft fusible mass, called *butter of tin.* It forms crystals of $SnCl_4,5H_2O$. It has value in dyeing for brightening and *fixing* red colors. Tin forms fluorides, which unite with other metallic fluorides, forming *stanno-fluorides*, isomorphous with corresponding silicofluorides, titanofluorides, and zircofluorides.

Oxides of tin: SnO, Sn_2O_3, SnO_2.

SnO, *stannous oxide* or monoxide, is soluble in acids, forming *ous* salts.

SnO_2, *stannic oxide* or dioxide, occurs as the common ore of tin, cassiterite. It may be obtained by heating tin in air. It is used, under the name of *putty powder*, to polish plate. It forms stannic acid, H_2SnO_3, and metastannic acid, $H_{10}Sn_5O_{15}$.

Sodium stannate, Na_2SnO_3, is an important mordant in calico-printing.

Sulphides of tin: **SnS**, tin monosulphide.

SnS_2, tin bisulphide, known as *mosaic gold*, is obtained by fusing a mixture of 12 parts of tin, 6 parts of mercury, 6 parts of ammonium chloride, and 7 parts of sulphur. The brilliant gold-colored scales thus produced are used for bronzing plaster casts.

Tests for tin compounds: STANNOUS COMPOUNDS:

(1) *The fixed caustic alkalies* yield a white precipitate soluble in an excess of the reagent.

(2) *Ammonia* and *carbonates of potassium, sodium*, and *ammonium* yield a white precipitate nearly insoluble in an excess.

(3) *Hydrogen sulphide* and *ammonium sulphide* give a black-brown precipitate soluble in ammonium sulphide containing excess of sulphur, from which solution it is reprecipitated as a yellow sulphide by acids.

(4) *Chloride of gold* gives the "*purple of Cassius.*"

STANNIC SALTS:

(1) *Fixed caustic alkalies* gives a white precipitate soluble in an excess.

(2) *Ammonia* and alkaline carbonates yield a white precipitate slightly soluble in an excess.

(3) *Ammonium carbonate* gives an insoluble white precipitate.

(4) *Hydrogen sulphide* yields a yellow precipitate.

(5) *Ammonium sulphide* yields a yellow precipitate soluble in an excess of the sulphide.

Tin—uses: (1) *Tinned plate,* which is iron covered with tin;

(2) *Pewter* and *Brttannia metal,* tin hardened with a little antimony;

(3) Cooking-vessels of copper, usually lined with tin;

(4) Thin sheets, as tin-foil;

(5) Common mirrors backed with tin amalgam;

(6) Tin salts in calico-printing and dyeing;

(7) Bronze, plumbers' solder, etc.;

(8) Lining for lead pipes.

TITANIUM. Symbol **Ti**. Atomic weight 48.

One of the rarer metals, titanium **occurs** as the minerals rutile and brookite, TiO_2; and in various titaniferous iron ores.

Preparation: By heating together titanium oxide, potassium fluoride, and potassium. It has a remarkable affinity for nitrogen, and when heated in air it absorbs both oxygen and nitrogen.

It forms two classes of **compounds**, *titanous* and *titanic*.

Chlorides of titanium: $\mathbf{Ti_2Cl_6}$, titanous chloride; $\mathbf{TiCl_4}$, titanic chloride. It forms corresponding fluorides and double salts called *titanofluorides,* analogous to the corresponding salts of silicon and zirconium.

The **oxides of titanium** are Ti_2O_3, sesquioxide or titanous oxide, and TiO_2, dioxide or titanic oxide.

The oxide, $\mathbf{TiO_2}$, has a limited use in imparting a yellow tint to porcelain.

It forms two **acids**, titanic and metatitanic acids, similar to stannic and metastannic acids.

The **occurrence of titanium in iron ores** renders the blast-furnace process difficult in the furnaces. It sometimes unites with nitrogen and carbon to form nitrocyanide of titanium, $Ti(CN)_2 + 3Ti_3N_2$, looking very much like metallic copper.

ZIRCONIUM. Symbol **Zr.** Atomic weight 90.

This metal, rarer than titanium, **occurs** as the mineral zircon, $ZrSiO_4$, and in a few rare minerals, such as fergusonite, endialyte, etc.

Properties: It exists in three states—amorphous, crystalline, and graphitoidal.

Amorphous zirconium burns to an oxide when heated in air. Crystalline zirconium is in the form of hard brittle scales resembling antimony in lustre and color. It burns in air at a high temperature, and takes fire at a red heat in chlorine gas.

Graphitoidal zirconium exists as steel-gray scales.

Uses: The mineral zircon is used as a gem known as *hyacinth*. The oxide, ZrO_2, has a limited application for illuminating purposes. Cotton fabric is saturated with zirconium oxide and then ignited. The cotton burns away, leaving a network of zirconium oxide, which becomes incandescent by heat from gas-flame and emits light.

THORIUM. Symbol **Th.** Atomic weight 231.5.

The very rare metal thorium **is found** as a silicate in the mineral thorite and in a few other scarce minerals, as euxenite, etc. It is a gray powder acquiring metallic lustre by pressure, specific gravity 7.66–7.79, insoluble in water, soluble in nitric and hydrochloric acids, but not attacked by caustic alkalies.

XI. METALS OF THE ANTIMONY GROUP.

Vanadium,
Antimony,
Bismuth,
Tantalum,
Niobium.

Characteristics: These metals act like phosphorus either as a triad or pentad, and if further compared with the non-metals nitrogen, phosphorus, and arsenic, they are seen to form a group of elements each of which is clearly related to the others through a regular gradation of properties.

This fact is indicated in the following table:

	Atomic weights.	Specific gravity.	Oxides.		Acids.	
Nitrogen	14	. .	N_2O_3.	N_2O_5.	HNO_3.	
Phosphorus	31	1.837	P_2O_3.	P_2O_5.	HPO_3.	H_3PO_4.
Vanadium	51.5	5.5	V_2O_3.	V_2O_5.	HVO_3.	H_3VO_4.
Arsenic	75	5.7	As_2O_3.	As_2O_5.		H_3AsO_4.
Niobium	94	. .		Nb_2O_5.	$HNbO_3$.	
Antimony	120	6.7	Sb_2O_3.	Sb_2O_5.	$HSbO_3$.	
Tantalum	182	. .		Ta_2O_5.	$HTaO_3$.	
Bismuth	208	9.82	Bi_2O_3.	Bi_2O_5.	$HBiO_3$.	

The antimony group appears to be on the dividing-line between the non-metallic and the metallic elements.

VANADIUM. Symbol V. Atomic weight 51.2.

Occurrence: It is widely diffused in rock as the minerals vanadinite, $Pb_5(VO_4)_3$; descloizite, $(Pb,Zn)_2(OH)VO_4$, and others.

It is a crystalline mass with a silver-white lustre, non-volatile, decomposing water at 100° C. It does not tarnish in air, burns in oxygen when heated, is insoluble in hydrochloric but soluble in nitric acid, giving a blue solution.

The **oxides of vanadium** are:

Monoxide, V_2O; Dioxide, V_2O_2;
Trioxide, V_2O_3; Tetroxide, V_2O_4, hypovanadic acid;
Pentoxide, V_2O_5, vanadic oxide.

Tests for vanadium compounds: *Vanadic* and *chromic acids* are the only acids whose solutions are red. Vanadic acid becomes blue, while chromic acid becomes green by deoxidation.

The salts are **used** in the manufacture of ink and as a dyestuff, giving one of the best blacks, called *vanadium black.*

ANTIMONY (STIBIUM). Symbol Sb. Atomic weight 122.

Occurrence and preparation: It is found as metallic antimony; as an oxide in the mineral valentinite, and chiefly as the sulphide, stibnite, Sb_2S_3

The ore is purified by fusion and afterward decomposed by fusion with iron and potassium carbonate, which retain the sulphur.

Properties of antimony: Bluish-white color, specific gravity 6.8, melting at 425° C. It is volatile at a red heat. It does not oxidize in air at ordinary temperatures. Its vapor burns in air to dense white fumes of Sb_2O_3. It is soluble in hydrochloric acid with the evolution of hydrogen. Nitric acid oxidizes it to antimonic acid, an allotropic form, which is curiously explosive when heated or scratched.

Uses of antimony: (1) In medicine.

(2) In type-founding and casts. The addition of a little metallic antimony to lead causes the molten alloy to expand at the moment of solidifying, and take an exceedingly sharp impression of the mould; either lead or antimony alone shrinks when solidified. Toughness is imparted to the type-metal alloy by adding tin.

(3) For other alloys: *Britannia metal* is antimony and tin; *Pewter* is antimony, tin, and copper; *Babbit's antifriction metal* for bearings is antimony, lead, tin, and copper.

(4) Antimony, electrolytically deposited as a black powder by metallic zinc, is used for giving plaster-casts the appearance of steel. It is called *antimony black.*

(5) As a sulphide, Sb_2S_3, it is used in the composition of *blue* or *Bengal lights.*

It forms two classes of **compounds,** *antimonous* and *antimonic.*

Antimonous hydride, SbH_3, antimonetted hydrogen, or stibine, is prepared from zinc, sulphuric acid, and a solution of an antimony salt. It is a colorless gas, burning with a green flame and producing white fumes of Sb_2O_3. This gas is analogous to ammonia, NH_3; phosphine, PH_3, and arsine, AsH_3.

Chlorides of antimony: The *trichloride,* $SbCl_3$, *antimonous chloride,* formerly called *butter of antimony,* which when crystalline was known as *powder of Algaroth;* and the *pentachloride,* $SbCl_5$.

Antimony also forms **iodides, bromides,** and **fluorides.**

Antimony trioxide, Sb_2O_3, or antimonous oxide, occurs as the minerals valentinite and senarmonite. It is dimorphous. When boiled with cream of tartar (acid potassium tartrate) it dissolves and crystallizes, and is called *tartar emetic.* It forms with water *orthoantimonous acid,* H_3SbO_3, and *metaantimonous acid,* $HSbO_2$. With water the pentoxide, Sb_2O_5, forms *antimonic acid,* H_7SbO_3.

Antimony tetroxide, Sb_2O_4, or antimonoso-antimonic oxide. The mineral cerrantite, or antimony ochre, may be regarded as a combination of Sb_2O_3 and Sb_2O_5.

Pentoxide or **antimonic oxide, Sb_2O_5,** is prepared by exposing metallic antimony to strong nitric acid. It forms an insoluble hydrate, which, by low heat, yields Sb_2O_5. The important salt is metantimoniate of potassium, $K_2O.Sb_2O_5,7H_2O$. It is the only precipitant of sodium salts.

Trisulphide or **antimonous sulphide, Sb_2S_3,** occurs as the mineral stibnite, the principal ore of antimony. It may be prepared by fusing antimony and sulphur. It is a heavy gray mineral with metallic lustre.

Pentasulphide or antimonic sulphide, Sb_2S_5, formerly called *sulphur aurantum,* is obtained by fusing together antimonous sulphide, sodium carbonate, slaked lime, and sulphur. It is an important ingredient of some firework mixtures. The artificial sulphide is orange-colored when produced in the laboratory by hydrogen sulphide in a solution of antimony. Heat changes it to the black form.

Tests for antimony: (1) *Sulphuretted hydrogen* gives an orange or brick-red precipitate, soluble in ammonium sulphide, and reprecipitated by acids.

(2) *Caustic potash* in hydrochloric acid solutions gives a white precipitate soluble in an excess.

(3) *Ammonia* yields a white precipitate insoluble in an excess.

(4) *Potassium and sodium carbonates* yield a white precipitate soluble in an excess.

(5) SbH_3 burns and deposits rings of metallic antimony on porcelain held in the flame.

(6) *Zinc and iron* reduce antimonial salts to the metallic state.

(7) *Blowpipe test:* An antimony salt on charcoal with *sodium carbonate* or *potassium cyanide* yields a brittle globule of antimony and thick white fumes of its oxide.

(8) *Metallic zinc* precipitates antimony from solution as a fine black powder.

BISMUTH. Symbol Bi. Atomic weight 210.

Occurrence: Bismuth is found in veins, in the metallic state, in Saxony; also as an oxide, a sulphide, and a carbonate. It is prepared from the ore by melting it out from the gangue rock.

Properties of bismuth: It is gray-white, brittle, having a specific gravity of 8.92, and is highly crystalline. It melts at 270° C., expands $\frac{1}{32}$ of its volume on solidifying, volatilizes at high temperatures, and is the most diamagnetic of all known bodies. It is little oxidized by air, but burns with a blue flame when strongly heated, and is soluble in nitric acid.

Trichloride of bismuth, $BiCl_3$, bismuthous chloride, is formed by bismuth and chlorine gas, or bismuth in aqua regia, and is decomposed by water, yielding a white precipitate of oxychloride:

$$BiCl_3 + H_2O = BiClO + 2HCl.$$

This precipitate is often formed from the salts by dilution with water.

The **oxychloride, $BiOCl$,** is used as a face powder (Blanche de Perle). It injures the skin.

Bichloride of bismuth, Bi_2Cl_4, is produced from the trichloride and metallic bismuth.

The **trioxide, Bi_2O_3,** bismuthous oxide, is prepared by igniting the nitrate, hydrate, or carbonate. It is a straw-yellow powder, fusible at high temperatures, in which state it is a powerful flux for silica.

With water it forms the *hydroxide*, Bi_2O_3,H_2O or $BiHO_2$, soluble in acids, forming *bismuthous* salts, $BiCl_3$, $Bi(NO_3)_3$, $Bi_2(SO_4)_3$, etc.

The **normal nitrate, $Bi(NO_3)_3,5H_2O$,** is decomposed by water, yielding insoluble *basic nitrate* or *subnitrate*, $Bi(OH)_2NO_3$.

The **basic nitrate** is sometimes used as a cosmetic. It is, however, injurious to the skin. Medicinally, it is used for stomach and bowel diseases.

Tests for bismuth in compounds: (1) *Water* gives a white precipitate to nitrate or chloride solutions.

(2) *Hydrogen sulphide* gives a black precipitate insoluble in ammonium sulphide.

(3) Blowpipe-test: On charcoal with bismuth flux (a mixture of KI and S) it yields a beautiful red coating.

Bismuth is **used** in conjunction with antimony in the construction of thermo-electro piles, these two metals forming the opposite extremes of the thermo-electric series. Its alloys are remarkable for their low fusion-point.

Rose's alloy, composed of 2 parts of bismuth, 1 part of lead, and 1 part of tin, melts at 93.7° C.

Wood's alloy, composed of 4 parts of bismuth, 2 parts of lead, 1 part of tin, and 1 part of cadmium, melts at 60.5° C.

They are used to make safety-plugs in boilers and for taking impressions from dies, etc.

TANTALUM. Symbol **Ta**. Atomic weight 182.

This very rare metal is of theoretical importance only. It occurs as the mineral tantalite, and is a black powder which when heated in air burns with a bright light into tantalic acid. It is insoluble in acids, excepting hydrofluoric.

NIOBIUM or COLUMBIUM. Symbol **Nb**. Atomic weight 94.

This very rare metal occurs in the rare mineral columbite. It is a black powder oxidizing with incandescence when heated in the air, and soluble in hot hydrofluoric acid and also in concentrated sulphuric acid.

XII. METALS OF THE PLATINUM GROUP.

Gold,	Palladium,	Ruthenium,
Platinum,	Rhodium,	Osmium.
	Iridium,	

These metals may be divided into three classes, according to their behavior with oxygen: (1) Gold and platinum do not combine directly with oxygen under any circumstances; (2) Palladium, rhodium, and iridium oxidize when heated in air or oxygen, but their oxides decompose by strong ignition into oxygen and the metal; (3) Ruthenium and osmium unite with oxygen to form volatile oxides which do not decompose even at the highest temperatures.

GOLD (AURUM). Symbol Au. Atomic weight 196.2.

Occurrence: This very widely diffused metal is almost universally found in small quantities in an uncombined state, the only exceptions being the tellurides, which also generally contain silver. It has been found in sea-water to the extent of about one grain of gold per ton of water.

Gold occurs to some extent in dust, grains, or nuggets; but the larger yield is from invisible particles diffused through veins of iron pyrites or quartz. The largest recorded Australian nugget weighed 2680 oz., while California produced one weighing 2340 oz.

Native gold is almost always alloyed with silver. The purest specimen from the Ural Mountains contained 98.9 per cent. of gold. California gold averages 88 per cent.; Australian gold averages 96 per cent.

Processes of Obtaining Gold.

Gold may be obtained from **river sand** by simple washing; or from **auriferous earth** by hydraulic mining. The earth, being displaced by water, and caused to flow through troughs containing mercury, dispenses with its gold, which forms an amalgam with the mercury, from which it is subsequently separated by distillation.

Gold with **quartz or veinstone** is collected by mercury after crushing or milling the rock. The gold in combination with sulphides of arsenic, iron, and copper minerals is not attacked by mercury.

The heavy material collected from the milling operation is called "concentrates," and is treated by the *chlorine process*, essentially as follows:

The concentrates, mainly of *iron pyrites* with small amounts of arsenic and copper, are roasted to convert all the metals into oxides. After thoroughly roasting, chlorine gas is brought into contact, transforming the gold into a soluble chloride, which is extracted from the mass by leaching with water, and precipitated by ferrous sulphate:

$$2AuCl_3 + 6FeSO_4 = 2Fe_2(SO_4)_3 + Fe_2Cl_6 + 2Au.$$

When these concentrates *contain silver* it is extracted from the leached material by solution in hyposulphite of sodium (see Silver).

Gold is *separated from silver* by a process called "parting." The crude bullion is melted with additional silver, so that the alloy shall consist of 3 parts of silver to 1 of gold. This alloy is then melted and granulated, and boiled with nitric or sulphuric acid, the silver going into solution and the gold remaining as a residue.

It may also be separated *electrolytically* by making the gold and silver alloy the anode and a plate of pure silver the cathode, the solution into which these are immersed being nitric acid. By passing a current of electricity through this circuit the silver is dissolved from the alloy and deposited on the silver cathode, the gold remaining as an insoluble powder.

Properties of gold: It is yellow and soft, the most malleable and ductile of all metals. It may be beaten into leaves $\frac{1}{282000}$ of an inch in thickness, or one grain may be drawn into wire 660 feet long. Gold melts at 1100° C., and is unaffected by air or water. It does not dissolve in any single acid, but it is soluble in aqua regia. With mercury it makes an amalgam. Light transmitted by gold-leaf assumes a greenish tinge. Gold is a trivalent element, forming two classes of compounds, *aurous* and *auric*.

Alloys of gold : Pure gold is too soft for practical uses, and is therefore hardened by alloying with copper or silver, the former yielding a ruddier and the latter a paler colored alloy. The coin standard for the United States is 900 fine—that is, 900 parts of gold in 1000 parts of gold and alloy. Coin silver is alloyed in the same proportion. Jewelers' gold is generally less fine. Its character is indicated by a standard called *carat*, pure gold being 24 carats fine. One carat, therefore, equals $\frac{1}{24}$ part of gold.

Monochloride of gold, AuCl, or aurous chloride, is obtained by evaporation of the trichloride to dryness and exposing it to a heat of 227° C. till the excess of chlorine is expelled. The yellowish-white mass is decomposed slowly in cold and rapidly in hot water into metallic gold and the trichloride.

Gold trichloride, $AuCl_3$, or auric chloride, is the most important compound of gold. It is obtained by dissolving gold in aqua regia, and appears as a red crystalline mass, deliquescent, soluble in water, alcohol, and ether, sensitive to light, and forming double salts with a number of metallic chlorides, called *chloroaurates*. This chloride is used in "toning" photographs, and also, when mixed with an excess of acid sodium or potassium carbonate, to gild small copper articles.

Gold monoxide, Au_2O, or aurous oxide, is a green powder partly soluble and easily decomposed into metallic gold and auric oxide.

Trioxide of gold, Au_2O_3, or auric oxide, is a chestnut-brown powder, reducible by heat or light, insoluble in nitric acid, but soluble in hydrochloric or hydrofluoric acid and in alkalies. When digested with ammonia it yields *fulminating gold*, Au_2O_3,-$4NH_3,H_2O$. This trioxide forms *aurate* salts, as potassium aurate, $K_2O,Au_2O_3,6H_2O$, or $KAuO_2,3H_2O$, the solution of which may be used for electro-gilding.

A *sodium aurous-thio-sulphate*, $Na_3Au(S_2O_3)_2,2H_2O$, is used in "fixing" daguerrotype pictures.

The **sulphides of gold** are: *Aurous sulphide*, Au_2S, a black precipitate, and *auric sulphide*, Au_2S_3, a yellow precipitate.

Tests for gold: (1) *Ferrous sulphate* gives a brown precipitate fusible to a metallic bead.

(2) *Stannous chloride* produces a brownish-purple precipitate, called "purple of Cassius."

(3) *Oxalic acid* slowly reduces gold to its metallic state.

Uses of gold: Gold has an extensive use as a metal for coinage, jewelry, ornamentation, dentistry, gold-leaf gilding; also for imparting a red tint to glass (giving the purple of Cassius), for enamel-painting, and for lining platinum stills in the final concentration of sulphuric acid. Its salts are used for "fixing and toning" in photography. The double cyanide of gold and potassium is used in electroplating.

PLATINUM. Symbol Pt. Atomic weight 196.7.

Occurrence: It occurs alloyed with palladium, rhodium, iridium, and iron, and as the very rare mineral sperrylite, an arsenide. The Ural Mountains yield the greater part of the world's supply. Platinum is *prepared* by a very complicated refining operation.

Properties of platinum: It is a steel-white metal, of specific gravity 21.5. It is malleable and ductile, fusible at 1775° C., and insoluble in all acids except *aqua regia*. It may be superficially oxidized by fused potassium hydroxide. When in a finely divided state, "platinum black" condenses gases within its pores to a remarkable extent, one volume absorbing 800 volumes of oxygen. Platinum is a tetrad, forming two series of salts, *platinous* and *platinic*. Its compounds are many, complicated, and mainly of theoretical interest.

Chlorides of platinum: Platinum dichloride or *platinous chloride*, $PtCl_2$, is prepared by the exposure of platinic chloride to heat.

The tetrachloride or *platinic chloride*, $PtCl_4$, is derived from a solution of platinum in *aqua regia*.

Both chlorides form double salts with metallic chlorides.

The **bromides** and **iodides** form analogous salts.

Oxides of platinum: The monoxide or *platinous oxide,* PtO; and the dioxide or *platinic oxide,* PtO_2.

The **sulphides** are PtS and PtS_2.

Ammoniacal platinum compounds: The chlorides, oxides, sulphates, etc., of platinum unite with two or more molecules of ammonia, forming compounds analogous to the mercurammonium compounds. With platinum and ammonium there are twelve distinct groups.

Tests for platinum compounds: (1) *Hydrogen sulphide or ammonium sulphide* generally forms a brown precipitate soluble in an excess of ammonium sulphide.

(2) *Zinc* precipitates metallic platinum.

(3) *The chloride of potassium or of ammonium, but not of sodium,* with a platinum compound yields a yellow granular precipitate.

Uses: It is indispensable in the laboratory. Platinum is used for making crucibles, dishes, capsules, wire, foil, etc.; for constructing stills for the final concentration of sulphuric acid; as the negative element in the Grove battery, and in construction of electrical apparatus. When used for stills, crucibles, etc., it is usually hardened with a little iridium. As a laboratory reagent the tetrachloride of platinum, $PtCl_4$, is used to separate potassium from sodium compounds (see test 3).

PALLADIUM. Symbol **Pd.** Atomic weight 106.2.

This rare metal, of little importance, is **found** alloyed with platinum and with gold. In color and appearance it closely resembles platinum, also in being very malleable and ductile, although more oxidizable. It oxidizes at a red heat in air, and is soluble in nitric and hydrochloric acids.

Palladium forms two classes of **compounds,** *palladious* and *palladic.*

The *Chlorides* are $PdCl_2$ and $PdCl_4$; the *Oxides,* PdO and PdO_2; the *Sulphide,* PdS.

Uses: On account of its constancy in air and its silver-white color, which is not affected by exposure to sulphuretted hydrogen, it is used for graduated surfaces for astronomical instruments, for plating silver goods, and in dentistry as an amalgam.

RHODIUM. Symbol **Rh.** Atomic weight 104.1.

This extremely rare metal is **found** alloyed with platinum. It is brittle, oxidizable, insoluble in acid, and less fusible and weldable than platinum.

Compounds: Its *chloride*, $RhCl_3$, forms double salts with potassium and ammonium compounds. Its *oxides* are the monoxide, RhO; sesquioxide, Rh_2O_3; dioxide, RhO_2. Its *sulphate*, $Rh_2(SO_4)_3,12H_2O$, forms compounds with ammonia.

Uses: (1) It is used for the thermo-electric pyrometer.

(2) Alloyed with steel in equal parts it gives a metallic surface which does not tarnish in air.

IRIDIUM. Symbol **Ir.** Atomic weight 196.7.

It is **found** in gold washings, and with platinum and osmium in an alloy called *iridosmine*. It is very infusible, and insoluble in acids.

Its **compounds** are of three forms: hypoiridious, iridious, and iridic. The dichloride, $IrCl_2$, is not obtained in a separate state. The other *chlorides* are the trichloride, $IrCl_3$ or Ir_2Cl_6, iridious chloride, and the tetrachloride, $IrCl_4$, or iridic chloride, which forms double salts with the chloride of potassium, sodium, and ammonium. The *oxides* are the monoxide, IrO, hypoiridious oxide; sesquioxide, Ir_2O_3, iridious oxide; dioxide, IrO_2, iridic oxide. The *sulphides* are IrS, Ir_2S_3, IrS_2. Its *ammoniacal compounds* are analogous to the same compounds of the platinum series.

Uses: Iridosmine is harder than steel, and is used for tipping gold pens. It can be electrolytically deposited as plate.

RUTHENIUM. Symbol **Ru.** Atomic weight 103.5.

It **occurs** with platinum and in iridosmine. It is the most refractory of all elements except osmium, and more easily oxidized than platinum or silver, but scarcely attacked by *aqua regia.*

Its **compounds** are *chlorides*, $RuCl_2$, $RuCl_3$, $RuCl_4$;
Oxides, RuO, Ru_2O_3, RuO_2, RuO_3, Ru_2O_7, RuO_4
Sulphides, RuS_2, Ru_2S_3.
It forms compounds with ammonia.

OSMIUM. Symbol **Os.** Atomic weight 198.6.

It is **found** associated with gold and platinum compounds. Its properties vary according to the manner in which it is prepared, but it is a hard, heavy, refractory metal, which, in a finely divided state, burns in air to a tetroxide.

Its **compounds** are *chlorides*, $OsCl_2$, $OsCl_3$, $OsCl_4$;
Oxides, OsO, Os_2O_3, OsO_2, OsO_3, OsO_4;
Sulphides, OsS, Os_2S_3, OsS_2, OsS_3, OsS_4.
It forms compounds with ammonia.

ORGANIC CHEMISTRY.

Derivation and meaning of the term organic chemistry: The chemistry of the compounds found in plants and animals was originally called organic chemistry, and this designation was introduced at the time of Lavoisier (about 1750), who first recognized the true composition of these substances. He showed that when they undergo combustion CO_2 and H_2O are always formed, and that their component elements are carbon, hydrogen, and oxygen, and sometimes nitrogen, with one or two others.

Soon after this it became evident that products of the animal and vegetable kingdoms possess a composition different from the mineral.

For a long time all attempts to *produce* these organic compounds *from* their elements failed, and the opinion therefore existed that they were different from mineral substances and could only be formed by a peculiar power, inherent in plants and animals, called the "vital force."

In the year 1828, Wöhler succeeded in producing urea from the mineral salt ammonium cyanate, and, following this, other syntheses soon showed that organic substances could be made from their elements without the aid of the "vital force."

At present we know that the peculiarities of organic compounds are dependent solely on the nature of their essential constituent, *carbon,* and that all substances belonging to plants and animals can be prepared from their elements.

Organic chemistry is therefore *the chemistry of the carbon compounds;* and it is separated from mineral chemistry on account of the vast number of its derivatives and their special properties as a class.

It is well to note the difference between *organic* and *organized* bodies.

Certain carbon compounds possess the power to assume, in the living organism, an "*organized*" or "*cellular*" structure, but the causes and conditions of this power have not yet been discovered.

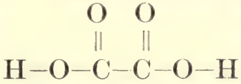
General characteristics of organic bodies: Organic bodies are in general distinguished by the facility with which they decompose under the influence of heat and chemical reagents; the more complex the structure the more readily are they decomposed or split up into simple groups.

They also easily burn, ferment, decay, and putrefy. They are generally composed of few elements, principally carbon, hydrogen, and oxygen, and sometimes nitrogen; also sulphur and phosphorus. *Artificial* compounds of these elements with most of the *metals* have also been prepared.

The **number** of known carbon compounds is very large—about sixty thousand. Many of them are of great practical interest in the arts, in medicine, and in physiological chemistry.

Classification of the carbon compounds: Dependent on the arrangement of the atoms in the molecule, the organic compounds are divided into two main groups: the *fatty* compounds or *chain* compounds, or *methane* derivatives; and the *aromatic* compounds or *ring* compounds, or *benzol* derivatives.

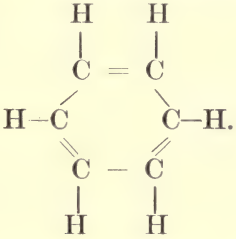
In the *first,* or fatty, group, derived from the hydrocarbon *methane*, CH_4, the atoms are arranged in the molecule in a chain :



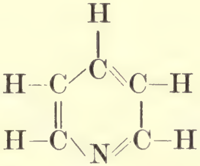
$$\mathrm{H{-}O{-}\overset{\overset{O}{\|}}{C}{-}\overset{\overset{O}{\|}}{C}{-}O{-}H}$$

(oxalic acid).

In the *second*, or aromatic, group, derived from the hydrocarbon *benzol*, C_6H_6, the atoms are arranged in a ring:



A *third group*, in which the atoms are arranged in a ring, but other atoms than carbon enter into the formation of the ring—*e. g.*,



,

pyridin, may conveniently be considered separately.

The numerous compounds belonging to the first and second of these groups are derived from CH_4 and C_6H_6, respectively, by the replacement of the hydrogen atoms by various elements and groups. These, therefore, may be considered as stock substances, from which all organic compounds can be formed.

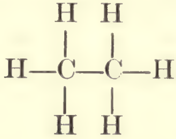
FATTY COMPOUNDS.

(Methane derivatives ; or chain compounds.)

I. HYDROCARBONS.

The hydrocarbons are **divided** into the (1) saturated and the (2) unsaturated hydrocarbons.

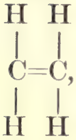
In the *saturated compounds* the carbons atoms are united by a single bond :



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & — & C & — & C & — & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

, ethane.

In the *unsaturated*, by double and threefold bonds:



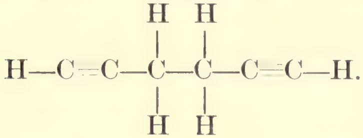
$$\begin{array}{ccc} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{array}$$

, ethene; and $H{-}C{\equiv}C{-}H$, ethine.

The hydrocarbons are **arranged** in homologous series—a series, that is, the terms of which differ from one another by CH_2.

The following list shows the *groups* of the hydrocarbons:

SATURATED.	UNSATURATED.			
The Paraffines. C_nH_{2n+2}	The Olefines. C_nH_{2n}	The Acetylenes. C_nH_{2n-2}	Olefinacetylene. C_nH_{2n-4}	Diacetylene. C_nH_{2n-6}
CH_4 Methane, marsh gas.	——	——		
C_2H_6 or CH_3CH_3 Ethane.	C_2H_4 or $CH_2=CH_2$ Ethene.	C_2H_2 or $CH{\equiv}CH$ Ethine, acetylene.		
C_3H_8 or $CH_3CH_2CH_3$ Propane.	C_3H_6 or $CH_3-CH=CH_2$ Propene.	C_3H_4 Propine.		
C_4H_{10} or $CH_3CH_2CH_2CH_3$ Butane etc.	C_4H_8 Butene, etc.	Etc.		
$C_{60}H_{122}$ Dimyricyl. The highest.				

In the *diacetylene* group C_nH_{2n-6} there occurs C_6H_6 (dipropargyl)  $\mathrm{H{-}C{\equiv}C{-}\underset{H}{\overset{H}{C}}{-}\underset{H}{\overset{H}{C}}{-}C{\equiv}C{-}H}$. This must not be confounded with its isomeric form C_6H_6, or *benzol,* from which the *aromatic compounds* are derived.

The paraffines: Many are found ready formed in American petroleum, natural gas, and other natural residues of the decomposition of vegetation.

Dependent on their carbon contents, they are gases, liquids, or solids. Thus *methane* is a gas; *butane,* a liquid; *dimyricyl,* a crystalline solid. They are very stable and not easily acted on by reagents. The substances known commercially as *cosmoline* and *vaseline* consist mainly of the higher members of the paraffine series and some of the olefines.

The remaining groups of hydrocarbons will not be considered.

II. HALOGEN DERIVATIVES OF THE HYDROCARBONS (HALOID ETHERS).

A **haloid ether** is a compound in which one or more of the hydrogen atoms of a hydrocarbon are replaced by a *halogen*—*i. e.,* Cl, Br, I.

Preparation: (1) By the action of halogens on hydrocarbons in sunlight (substitution-products);

(2) By the addition of a halogen or a halogen acid to unsaturated hydrocarbons:

$$C_2H_4 + Cl_2 = C_2H_4Cl_2;\ C_2H_4 + HBr = C_2H_5Br.$$

Properties: Haloid ethers are mostly colorless, ethereal-smelling liquids, and insoluble in water. With caustic alkalies they give unsaturated hydrocarbons; with moist silver oxide they yield alcohols.

Chloroform, $CHCl_3$; *iodoform,* CHI_3 (a yellow solid); and *bromoform,* $CHBr_3$, are haloid ethers derived from methane and used in medicine.

DERIVATIVES OF THE HYDROCARBONS CONTAINING OXYGEN.

In the hydrocarbons, saturated and unsaturated, and their halogen substitution-products, we have considered the simplest compounds of the fatty series.

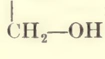
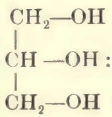
By replacing hydrogen atoms of the hydrocarbons by the group $-O-H$, called *hydroxyl*, a basis for the further division of the methane derivatives into the compounds containing oxygen is furnished:

(1) The hydroxyl group is either joined to a *single carbon atom*, replacing one of the hydrogen atoms united to the carbon; or

(2) With the same carbon atoms *several hydroxyl groups* are linked, replacing two or three of the hydrogen atoms.

(1) The important class called **the alcohols** constitute the first group, of which water, $H-O-H$, may be considered the simplest member. According to the number of hydroxyl groups they contain, alcohols are called mono, di, tri, tetra, penta, or hexatomic alcohols. But in every case it will be observed for each $-O-H$ there is a corresponding carbon atom, a single combining hydrogen atom of which has been replaced by hydroxyl.

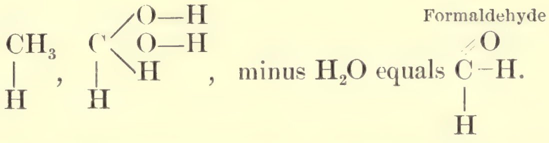
The following table shows the relation of the different classes of alcohols derived from the hydrocarbons of the paraffin series:

Hydrocarbon.	Alcohol.
CH_4	$CH_3—OH$, the simplest monatomic alcohol;
C_2H_6	 $\begin{array}{l} CH_2—OH \\ \vert \\ CH_2—OH \end{array}$: Ethylenglycol, the simplest diatomic alcohol;
C_3H_8	 $\begin{array}{l} CH_2—OH \\ \vert \\ CH\ —OH \\ \vert \\ CH_2—OH \end{array}$: Glycerin, the simplest triatomic alcohol;

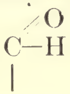
Hydrocarbon.	Alcohol.	
C_4H_{10}	CH_2-OH $\vert$ $CH-OH$ $\vert$ $CH-OH$ $\vert$ CH_2-OH	: Erythrite, the simplest tetratomic alcohol;
C_5H_{12}	CH_2-OH $CH-OH$ $CH-OH$ $CH-OH$ CH_2-OH	: Arabite, the simplest pentatomic alcohol;
C_6H_{14}	CH_2-OH $CH-OH$ $CH-OH$ $CH-OH$ $CH-OH$ CH_2-OH	: Mannite, the simplest hexatomic alcohol.

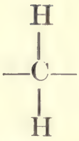
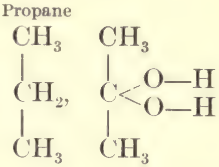
(2) The important classes called **aldehydes, ketones,** and **organic acids** belong to the second group. In these bodies two or three hydroxyl groups replace two or three hydrogen atoms joined to the same carbon atoms, as the following formulæ will make clear. This is followed by a splitting off of a molecule of water, leaving an oxygen atom in each case united with two bonds of the carbon atom.

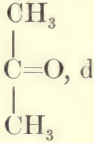
Methane: (*a*) Two hydroxyl groups replace two hydrogen atoms of a terminal $—CH_3$ group; thus:



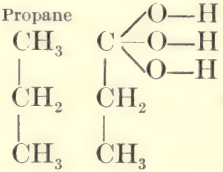
$$\begin{array}{c}CH_3\\|\\H\end{array},\quad \begin{array}{l}C\left\langle\begin{array}{l}O-H\\O-H\\H\end{array}\right.\\|\\H\end{array},\quad \text{minus } H_2O \text{ equals } \begin{array}{l}\quad\text{Formaldehyde}\\ \quad /\!/O\\C-H.\\|\\H\end{array}$$

In this way bodies are formed called **aldehydes,** containing the group  $\begin{array}{l}\quad /\!/O\\C-H\\|\end{array}$, *e. g.*, CH_3CHO, ethyl aldehyde.

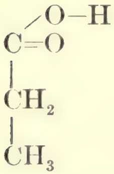
(*b*) Two hydroxyl groups replace two hydrogen atoms of an intermediate  $\begin{array}{c}\mathrm{H}\\|\\—\mathrm{C}—\\|\\\mathrm{H}\end{array}$ group, thus: 

minus H_2O equals  $\begin{array}{l}\mathrm{CH_3}\\|\\\mathrm{C{=}O}\\|\\\mathrm{CH_3}\end{array}$, dimethyl ketone or acetone.

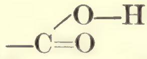
The **ketones** are in this manner formed, bodies characterized by the group $=CO$, *e. g.*, $C_2H_5COC_2H_5$, diethyl ketone.

(*c*) Three hydroxyls replace three hydrogen atoms of a terminal CH_3 group, thus: 

minus H_2O equals



, propionic acid.

The **organic acids** characterized by the group , called *carboxyl*, are thus formed—*e. g.*, CH_3COOH, acetic acid.

The alcohols, aldehydes, and ketones are neutral bodies; the organic acids are well-marked acids forming salts like the mineral acids.

Since the aldehydes, ketones, and organic acids are closely related to the alcohols, occurring as oxidation-products of the same, these bodies will be considered after the corresponding alcohols; and the different classes of alcohols will serve as a means of grouping the remaining bodies of the fatty series.

In similar fashion alcohols, aldehydes, ketones, and organic acids, corresponding to the *unsaturated* hydrocarbons, are formed.

Since each alcohol and each one of the groups just outlined has its derivatives, it will be seen how vast is the number of substances considered under the chemistry of the carbon compounds, especially if one considers the compounds formed by substituting similar groups in the *benzene* derivatives and the compounds in which atoms of the halogens, sulphur or nitrogen, are introduced.

III. THE MONATOMIC ALCOHOLS (and their derivatives).

Methyl alcohol, CH_3OH, is prepared from crude wood-vinegar in the destructive distillation of wood. It is a light, colorless liquid, boiling at 66° C., similar to ethyl alcohol in most of its properties, and is often used for it in the arts because it is cheaper.

Ethyl alcohol (C_2H_5OH), *common alcohol*, is produced in the fermentation of sugar: $C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2$.

Properties: It is a colorless, limpid liquid, with a pungent and agreeable odor and taste. Its specific gravity is 0.789 at 20° C. It boils at 78.3° C. It is very inflammable, burning with a smokeless flame giving intense heat. It mixes with water in all proportion, is a great solvent, dissolving many salts, alkalies, resins, alkaloids, essentials oils, and other substances.

It acts on the body as a narcotic poison; in small quantities it is a stimulant. It is an antiseptic, and is used for the preservation of substances subject to decay.

The proportion of alcohol in **various beverages** is:

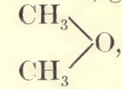
	Alcohol percentage by volume.
New York lager beer	5.86
Guinness's stout	6.81
Allsopp's ale	8.25
Claret	8.07– 9.70
Rhine wine (white)	11.07

	Alcoholic percentage by volume.
Champagne	11.75
Madeira	18.81–19.11
Port	20.03
Sherry	22.90
Whiskey	50–58
Brandy	46–55

Cholesterin, $C_{27}H_{45}OH$, a monatomic alcohol, occurs in a free state in the human body. It is present in the bile, in the blood, brain, and in small quantities in many tissues. It is a white crystalline substance.

A mixture of the esters of cholesterin with the several fatty acids contained in ordinary fat is used in medicine under the name of *lanoline*, the purified fat of the wool of the sheep.

Alcohol Derivatives.

The hydrogen atom of the hydroxyl can be replaced by metals, forming **alcoholates**—*e. g.*, C_2H_5ONa, sodium ethylate; or by alcohol radicals, giving **ethers**, oxides therefore of this radical—*e. g.*,  $\begin{matrix}CH_3\\CH_3\end{matrix}\!>\!O$, methyl ether.

If the hydrogen atom is replaced by acid radicals, **compound ethers** (*esters*) are formed: $C_2H_5ONO_2$, ethyl nitrate, C_2H_5-OCH_3CO, the ethyl ester of acetic acid.

Ethyl ether is prepared by heating alcohol and sulphuric acid to 140° C.; water is abstracted and ether formed:

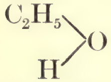
$$2C_2H_5OH + H_2SO_4 = (C_2H_5)_2O + H_2SO_4,H_2O.$$

Properties: It is a clear, colorless liquid; specific gravity, 0.792. It boils at 35° C. It is very combustible, forming an explosive mixture with air. It is soluble in alcohol; only slightly in water. It is a good solvent for oils and fats. It also dissolves sulphur and phosphorus.

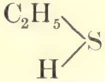
It is *used* for dissolving gun-cotton in the preparation of collodion, and in medicine as an anæsthetic.

Sulphur Compounds of the Alcohol Radical.

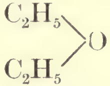
Corresponding to the alcohols and ethers are **sulphur compounds,** in which a sulphur atom replaces the oxygen atom :



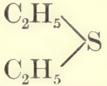
Ethyl alcohol.



Ethyl mercaptan or thio alcohol.



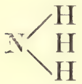
Ethyl ether.



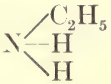
Ether sulphide or thio ether.

Nitrogen Compounds of the Alcohol Radical.

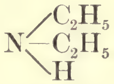
Among these nitrogen compounds may be mentioned the class called **amines,** bodies built up on the ammonia type, in which one or more of the hydrogen atoms are replaced by one or more alcohol radicals :



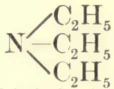
Ammonia.



Ethylamine.



Diethylamine.



Triethylamine.

Properties : The amines are bodies very like ammonia. The lower members are gases, very soluble in water, with an ammoniacal odor ; but differ from ammonia in being inflammable. The higher members are liquids. They are strongly basic and form salts with acids.

The Aldehydes (*of the Monatomic Alcohols*).

Aldehydes may be prepared by the oxidation of the primary alcohols :

$$C_2H_5OH + O = CH_3CHO.$$

They are colorless, neutral, volatile liquids.

Formaldehyde, HCHO, a gas with a sharp, penetrating odor, is found commercially as formalin, a 40 to 45 per cent. solution in water. It is used as an antiseptic and preservative.

Paraldehyde, $(CH_3CHO)_3$, a polymeric form of ethyl aldehyde (CH_3CHO), is used in medicine as a hypnotic.

By the substitution of 3 atoms of chlorine for the H atoms of ethyl aldehyde a body is formed, trichloracetaldehyde or **chloral.** This combined with a molecule of water is used also as a hypnotic, $C.Cl_3CHO,H_2O$, under the name *chloral hydrate.*

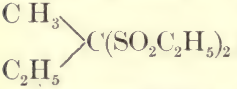
Ketones (*of the Monatomic Alcohols*).

They are mostly volatile liquids, insoluble in water; on oxidation they break up into different acids.

Acetone, dimethyl ketone, $CH_3-CO-CH_3$, occurs in considerable quantities in diabetic urine.

It is a colorless, limpid liquid, with a pungent odor, lighter than water, and boils at 53° C.

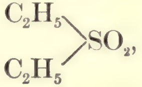
It is used in the *preparation* of CHI_3, iodoform; $CHCl_3$, chloroform; and the *hypnotics*, sulfonal—acetone diethyl sulphone, $(CH_3)_2C(SO_2C_2H_5)_2$; trional, methyl ethyl ketone diethyl sulphone or diethyl sulphone methyl ethyl methane,



$$\begin{matrix} CH_3 \diagdown \\ \\ C_2H_5 \diagup \end{matrix} C(SO_2C_2H_5)_2$$

; and tetronal.

Corresponding to the ketones, we have the *sulphones*, in which $>SO_2$ replaces the group $>CO$—*e. g.*,



$$\begin{matrix} C_2H_5 \diagdown \\ \\ C_2H_5 \diagup \end{matrix} SO_2,$$

diethyl sulphone.

The Organic Acids (*of the Monatomic Alcohols*).

($C_2H_{2n+1}COOH$: the fatty acids.)

The *lower* members are colorless liquids; the *intermediate*, thick, oily liquids; the *higher* ones, crystalline solids. Most are insoluble in water, but dissolve in alcohol. The alkali salts of the higher fatty acids (like palmitic and stearic) are called *soaps;* if a potassium salt, soft soap; if a sodium salt, hard soap.

Acetic acid, CH_3COOH, is produced by the slow oxidation of alcohol:

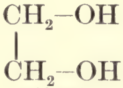
$$C_2H_5OH + O_2 = CH_3COOH + H_2O.$$

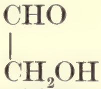
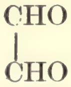
Vinegar is a dilute solution of acetic acid. Acetic acid below 15° C. is a crystalline solid ; above that temperature it is a thin, colorless liquid, with a pungent odor and fiery taste. It is miscible with water, alcohol, and ether, and dissolves some gums and resins. It is used in medicine as a cauterizing agent.

Among the derivatives of the fatty acids may be mentioned the **amides**, bodies built up on the ammonia type, in which one or more of the hydrogen atoms are replaced by organic acid radicals—*e. g.*, $NH(CH_3CO)_2$, diacetamide. The amides of the fatty acids are mostly stable crystalline bodies.

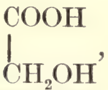
IV. THE DIATOMIC ALCOHOLS (and their derivatives).

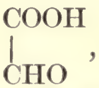
By the oxidation of the diatomic alcohols (just as in the case of the monatomic alcohols) are derived *aldehydes*, *ketones*, and *acids*.

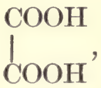
The simplest **diatomic alcohol** is  $\begin{array}{l} CH_2-OH \\ | \\ CH_2-OH \end{array}$.
(Glycol).

The **aldehydes** are  $\begin{array}{l} CHO \\ | \\ CH_2OH \end{array}$, oxyaldehyde, and  $\begin{array}{l} CHO \\ | \\ CHO \end{array}$, dialdehyde.
(Glycolylaldehyde); (Glyoxal).

The **acids** are oxy-organic acids, aldehyde-organic acids, and dibasic organic acids :


$\begin{array}{l} COOH \\ | \\ CH_2OH \end{array}$,
Glycolic acid;


$\begin{array}{l} COOH \\ | \\ CHO \end{array}$,
Glyoxalic acid;


$\begin{array}{l} COOH \\ | \\ COOH \end{array}$,
Oxalic acid.

Acids are called mono-, di-, or triatomic, according to the number of *carboxyl groups* they contain.

The Oxyorganic Acids.

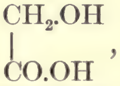
Lactic acid, $C_2H_4(OH)COOH$, is derived from propylenglycol, $C_3H_6(OH)_2$, by oxidation. Two acids, *a* and *β*, are possible for this formula, depending on the position of the hydroxyl group: (*a*) $CH_3CH(OH)COOH$; and (*β*) $CH_2OH\text{-}CH_2COOH$.

Ordinary or *a-lactic acid* is produced from sugar by a particular ferment. It occurs in sour milk. It can be produced synthetically. It is a syrupy liquid, intensely sour. It is soluble in water, alcohol, and ether.

Sarco-lactic acid, occurring in muscle, is isometric with the preceding, differing in the solubility of its calcium and zinc salts and in having a distinct rotary action on polarized light.

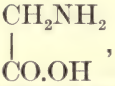
Amido Fatty Acids or the Amine Fatty Acids.

These are formed by the substitution of the amido group NH_2 in the place of the hydroxyl group OH of the oxyorganic acids:



$$\begin{array}{l}CH_2.OH\\ |\\ CO.OH\end{array},$$

Glycolic acid;

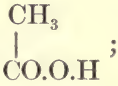


$$\begin{array}{l}CH_2NH_2\\ |\\ CO.OH\end{array},$$

Glycolæmin acid.

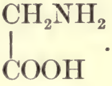
It is simpler to consider them as derived from the fatty acids by the replacement of a hydrogen atom by the amido group:

Acetic acid,



$$\begin{array}{l}CH_3\\ |\\ CO.O.H\end{array};$$

amido acetic acid,



$$\begin{array}{l}CH_2NH_2\\ |\\ COOH\end{array}.$$

Glycin, *glycocoll, amido acetic acid*, CH_2NH_2COOH, enters into the formation of several important substances occurring in the animal body, more especially hippuric and glycocholic acids. It is a crystalline substance, soluble in 4 parts of cold water, and having a sweetish taste.

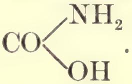
Sarkosin, *methyl amido acetic acid*, is also of interest in physiological chemistry, $CH_2NHCH_3.COOH$.

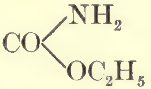
Leucin, *amido caproic acid,* $C_5H_{10}NH_2COOH$, is a characteristic product of the decomposition of proteids.

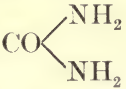
Carbonic Acid and Its Derivatives.

The **salts** and **ester** of carbonic acid are derived from the hydrated carbonic acid, $CO(OH)_2$, not found in a free state.

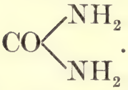
It may also be regarded as HO.COOH, *oxyformic acid.* It is a weak dibasic acid. It forms primary and secondary salts, CO_2HK, CO_3K_2.

Amido derivatives of carbonic acid: By replacing one of the hydroxyl groups by the amido group NH_2, *carbamic acid* is formed:  $CO\begin{matrix}\diagup NH_2\\ \diagdown OH\end{matrix}$.

The **ethyl ester** of carbamic acid is  $CO\begin{matrix}\diagup NH_2\\ \diagdown OC_2H_5\end{matrix}$; and is used in medicine, under the name of *urethane,* as a hypnotic.

Urea, carbamide,  $CO\begin{matrix}\diagup NH_2\\ \diagdown NH_2\end{matrix}$, is the chief nitrogenous constituent of urine in mammalia. The average daily excretion in an adult human being is 30 grams.

Preparation: (1) From urine by concentration to a syrupy state, extraction of the residue with absolute alcohol, and concentration of the alcoholic extract until the urea crystallizes out.

(2) By heating cyanamide with water, $CNNH_2 + H_2O =$  $CO\begin{matrix}\diagup NH_2\\ \diagdown NH_2\end{matrix}$.

Properties: Urea forms transparent crystals, soluble in water and alcohol. It has no smell, but a saline taste.

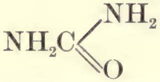
Urea forms salts with acids, by combining directly with them:

$CO(NH_2)_2.HNO_3$, nitrate of urea;
$CO(NH_2)_2.HCl$, chloride of urea.

By replacing the oxygen of urea with sulphur, *thioureas* are formed. They are similar to urea in many respects.

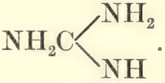
Among the **derivatives of urea** may be mentioned the ureide of carbonic acid, $NH_2.CO.NHCOOH$; the amide of which, $NH_2CO.NH.CONH_2$, is known as *biuret.*

Guanidin: This may be considered as the amide of amido-carbonic acid:



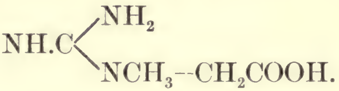
;

Amido-carbonic acid.
Carbamide or urea.



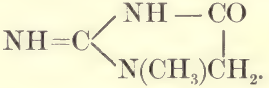
Guanidin.

From guanidin **keratin** (methyl guanidin acetic acid) is derived:



This body is a characteristic constituent of muscle and muscle-extracts.

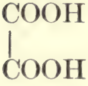
The *dehydrated form* of kreatin is known as **kreatinin**:



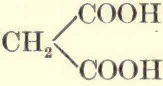
It occurs as a constant constituent of urine.

Dibasic Organic Acids, $C_nH_{2n}(COOH)_2$.

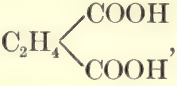
These acids contain *two* carboxyl groups, and hence are "dibasic":



, oxalic acid ;



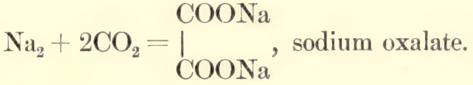
, malonic ;



, succinic, etc.

Oxalic acid, $(COOH)_2$, occurs in plants as potassium and other salts. The calcium salt is not infrequently found in urine, and enters into the formation of many urinary calculi.

It is formed synthetically by the action of CO_2 on sodium:

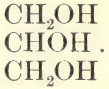


$$Na_2 + 2CO_2 = \begin{matrix} COONa \\ | \\ COONa \end{matrix}, \text{ sodium oxalate.}$$

It forms crystals with H_2O. It is soluble in water, and the solution is strongly acid. The soluble salts and the free acid are very poisonous. The *antidote* is lime-water, insoluble calcium oxalate being formed.

V. THE TRIATOMIC ALCOHOLS (and their derivatives).

Glycerin, or *propenyl alcohol*, $C_3H_5(OH)_3$; or



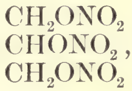
$$\begin{matrix} CH_2OH \\ CHOH \\ CH_2OH \end{matrix}.$$

It is obtained by boiling fat with caustic alkalies (saponification):

$$\underset{\text{(The fat, tristerin.)}}{C_3H_5(C_{17}H_{35}.CO.O)_3} + 3KOH = \underset{\text{(Glycerin.)}}{C_3H_5(OH)_3} + \underset{\text{(Potassium sterate, soft soap.)}}{3(C_{17}H_{35}.COOK)}.$$

It is a thick, syrupy liquid, a little heavier than water, with a sweet taste. It is soluble in all proportions in water and alcohol.

Esters of glycerin, *nitro-glycerin,* $C_3H_5(NO_3)_3$ or

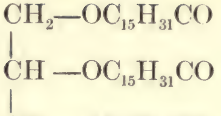


$$\begin{matrix} CH_2ONO_2 \\ CHONO_2 \\ CH_2ONO_2 \end{matrix},$$

is formed by the addition of glycerin to a mixture of sulphuric and nitric acids. It is a yellowish liquid. It is insoluble in water; slightly soluble in alcohol. It is a well-known explosive.

Under the name of *glonoin,* it is used in medicine.

The **neutral fats,** *tri-sterin, tri-palmitin,* and *tri-olein* are *esters of glycerin* (combinations in which the hydrogen of the alcohol is replaced by the radicals of the higher fatty acids:



$$\begin{array}{l} CH_2—OC_{15}H_{31}CO \\ | \\ CH —OC_{15}H_{31}CO \\ | \\ CH_2—OC_{15}H_{31}CO. \end{array}$$

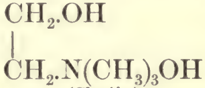
Tri-palmitin (solid).

$C_3H_5(OC_{17}H_{35}CO)_3$.
Tri-sterin (solid).

$C_3H_5(OC_{17}H_{33}CO)_3$.
Tri-olein (liquid).

Most natural fats are a mixture of these.

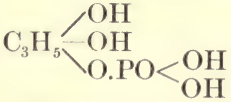
The complex body, **lecithin**, a constituent of the brain, nerves, blood-corpuscles, and the yolk of egg, is an ester-like compound formed by the combination of cholin (oxyethyl trimethyl ammonium hydroxide),



$$\begin{array}{l} CH_2.OH \\ | \\ CH_2.N(CH_3)_3OH \end{array}$$

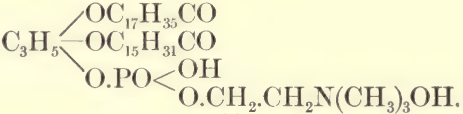
(Cholin),

with glycerophosphoric acid,



(Glycerophosphoric acid),

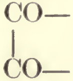
in which the two hydrogen atoms of the glycerin are replaced by the radicals of the higher organic acids :



(Lecithin).

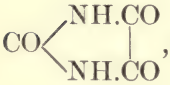
The Uric Acid Group.

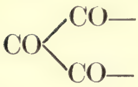
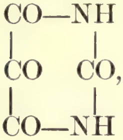
The *hydrogen atoms of urea* can be replaced by *acid radicals*, forming the so-called *ureides.* Thus the substitution of the radical

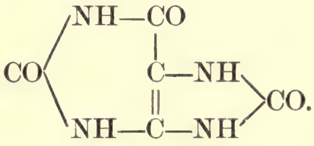


$$\begin{array}{l} CO— \\ | \\ CO— \end{array}$$

derived from oxalic acid gives the ureide



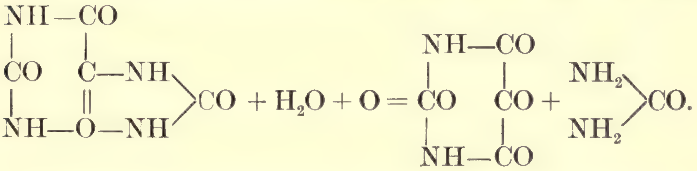
, known as *parabamic acid ;* and the substitution of the radical  derived from mesoxalic acid gives the ureid , called *alloxan*.

Uric acid: $C_5H_4N_4O_3$; 

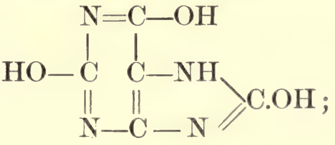
This acid is the chief constituent of the urine of birds and reptiles; it occurs in small amount in the urine of mammalia. Traces have been found in the spleen, lungs, heart-muscle, and liver. It is the chief ingredient of some renal calculi; and accumulations of uric acid salts occur in various parts of the body in gout.

It is a white crystalline powder, tasteless and odorless. Soluble in water with difficulty; but readily soluble in many of the salts of the alkalies.

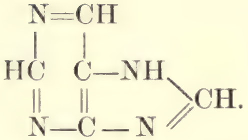
By *oxidation* uric acid is decomposed into alloxan and urea:



To connect uric acid with the constitution of another set of compounds, it may be considered as trioxypurin,

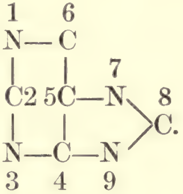


purin being



This *purin* is formed by substituting hydrogen atoms in a so-called *purin nucleus*, in the places marked 2, 6, 7, and 8.

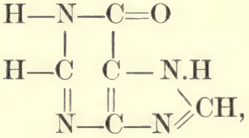
Purin nucleus :



The xanthin group: The bodies *guanin, xanthin, hypoxanthin, adenin, theobromin,* and *caffein* are closely related to uric acid and to each other. The first four are products of the downward destructive metabolism of nuclear material in the karyoplasm of cells; and are spoken of as the *nuclear bases.* The last two are found in the seeds and leaves of certain plants (coffee).

They can all be derived from the *purin nucleus.*

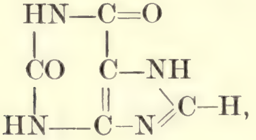
Hypoxanthin or oxypurin, $C_5H_4N_4O$.



hydrogen in 1, 2, 7, 8.

oxygen in 6.

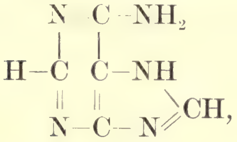
Xanthin or dioxypurin, $C_5H_4N_4O_2$.



H in 1, 3, 7, 8.

O in 2, 6.

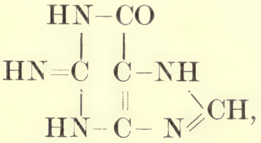
Adenin or amino-purin, $C_5H_5N_5$.



H in 2, 7, 8.

NH_2 in 6.

Guanin or amino-oxypurin, $C_5H_5N_5O$.

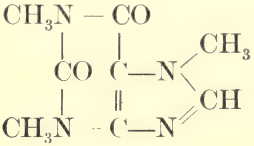


H in 1, 3, 7, 8.

NH in 2.

O in 6

Caffiein or trimethyl dioxypurin, $C_8H_{10}N_4O_2$.



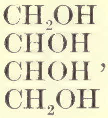
H in 8.

CH_3 in 1, 3, 7.

O in 2, 6.

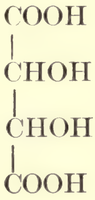
VI. THE TETRATOMIC ALCOHOLS (and their derivatives).

Derived from the *tetratomic alcohol*, **erythrit**, , are the *dioxy dibasic organic acids:*



$$\begin{array}{l} CH_2OH \\ CHOH \\ CHOH \\ CH_2OH \end{array}$$

Tartaric acid:



$$\begin{array}{l} COOH \\ | \\ CHOH \\ | \\ CHOH \\ | \\ COOH \end{array}$$

; $C_2H_2(OH)_2.(COOH)_2$.

Four modifications of tartaric acid exist, known as:

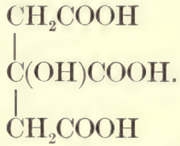
1. Dextrotartaric acid.
2. Lævotartaric acid.
3. Paratartaric or racemic acid.
4. Inactive tartaric acid.

They show differences in their solubilities and in their effect on polarized light.

Ordinary or **dextrotartaric acid** occurs in grapes, pineapples, etc., as a potassium salt. It is prepared from argol (acid potassium tartrate), deposited by wine. It can be prepared synthetically from bibromsuccinic acid. It is a crystalline compound, soluble in water, with an acid taste and reaction. It is used in medicine.

Among its *compounds*, potassium bitartrate (cream of tartar), $HKC_4H_4O_6$; sodium potassium tartrate (Rochelle salt), $NaKC_4H_4O_6$; and potassium tartrate, $K_2C_4H_4O_6$, are used in medicine as *saline purgatives;* and antimony and potassium tartrate, *tartar emetic*, $KSbO.C_4H_4O_6$, is used as an emetic.

Citric acid: This is an oxytriatomic acid,



$$\begin{array}{l} CH_2COOH \\ \vert \\ C(OH)COOH. \\ \vert \\ CH_2COOH \end{array}$$

This acid is present in the juices of many berries and fruits, such as limes, lemons, cranberries, gooseberries, currants, strawberries, and red elderberries.

It is prepared commercially from lemon and lime juices. It is crystalline, odorless, and has an agreeable acid taste.

VII. THE PENTATOMIC ALCOHOLS.

The derivatives of the **pentatomic alcohols** (pentite, $C_5H_7(OH)_5$), are of no practical interest.

VIII. THE HEXATOMIC ALCOHOLS (and their derivatives).

Three of the hexatomic alcohols, corresponding to the formula $CH_2OH.(CHOH)_4CH_2OH$, occur in nature as **mannite,**

dulcite, and **sorbit.** They are like the sugars in some of their characteristics, having a sweet taste, but differing in not reducing Fehling's solution and in not being fermented by yeast. They can be obtained by reducing the corresponding aldehydes and ketones, which occur in nature as the sugars.

The Aldehydes and Ketones (*of the Hexatomic Alcohols*).

The *pentaoxyaldehydes* and *pentaoxyketones*, derived by oxidation from the hexatomic alcohols, have been known for a long time under the name of **carbohydrates**, usually subdivided into the three classes—glucoses, saccharoses, and starches or amyloses.

Glucoses.

The two most important are *dextrose* and *lævulose.*

Dextrose (glucose, grape-sugar):

$C_6H_{12}O_6[COH-(CHOH)_4-CH_2OH]$, pentaoxyaldehyde.

It occurs in many sweet fruits, in honey, and in the urine in the disease diabetes mellitus.

It rotates the plane of polarized light to the right. It is soluble in water, slightly soluble in alcohol, and insoluble in ether. Under the influence of yeast, an aqueous solution of dextrose breaks down into ethyl alcohol and carbon dioxide:

$$C_6H_{12}O_6=2C_2H_5OH+2CO_2.$$

When boiled with an alkaline solution of potassio-cupric tartrate (Fehling's solution), it precipitates red cuprous oxide.

Lævulose (fruit-sugar):

$C_6H_{12}O_6[CH_2OH.(CHOH)_3CO.CH_2OH]$ or pentaoxyketone.

It occurs mixed with dextrose in many fruits and honey. It behaves in general like dextrose, but is distinguished by rotating the plane of polarized light to the left.

Both **dextrose** and **lævulose** are produced by the action of dilute mineral acids on cane-sugar, causing the sugar to take up a molecule of water:

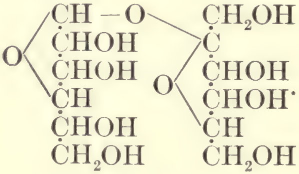
$$C_{12}H_{22}O_{11}+H_2O=C_6H_{12}O_6+C_6H_{12}O_6.$$

Mixed together, lævulose and dextrose are about half as sweet as cane-sugar.

Saccharoses.

Saccharoses, or sugars, $C_{12}H_{22}O_{11}$: These are made up of 2 molecules of glucose minus a molecule of water. The most important are cane-sugar, maltose, and lactose.

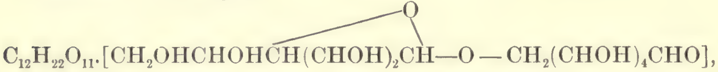
Cane-sugar:



It is found in the juices of many plants. It is prepared chiefly from *sugar-cane* and the *sugar-beet.* It does not directly undergo alcoholic fermentation; it does not reduce Fehling's solution. It is crystalline, has a pure, sweet taste, and is soluble in water and, with difficulty, in alcohol. Heated to about 200° C., it is converted into a brown amorphous mass called caramel. It rotates the plane of polarized light to the right.

Maltose, $C_{12}H_{22}O_{11}$: This is the sugar formed by the action of the ferments of the saliva and pancreatic juice on starch.

Lactose, milk-sugar,



$C_{12}H_{22}O_{11}.[CH_2OHCHOHCH(CHOH)_2CH—O—CH_2(CHOH)_4CHO]$,

is the sugar found in milk. Fehling's solution is reduced by both maltose and lactose.

The Amyloses, or Starches $(C_6H_{10}O_5)_n$.

The most important are *starch, cellulose,* and *gums.*

Starch occurs in the cells of many plants in the form of roundish microscopic bodies having an organized structure.

It is insoluble in cold water, but dissolves in hot water. It is precipitated from its solutions by alcohol. It gives a blue color with iodine. It is an important article of food. It is converted into dextrose and dextrine by the action of dilute mineral acids and certain ferments.

Glycogen $(C_6H_{10}O_5)_n$ is found in the livers of mammalia. It is very similar to starch, but gives a port-wine color with iodine.

Cellulose $(C_6H_{10}O_5)_n$ is the woody portion of plants and makes up their cells. Linen and cotton are very pure examples of cellulose. It is not readily attacked by agents nor dissolved by ordinary solvents. It is soluble in ammonio-sulphate of copper. With nitric acid it yields an ester, the explosive compound *gun-cotton.*

Gums, $(C_6H_{10}O_5)_n$: The gums occur in many plants. They are amorphous, transparent, and soluble in water, forming a sticky solution.

Several of the gums, such as gum-arabic, gum-senegal, gum-tragacanth, are used in medicine as *demulcents.*

Dextrine is a gum occurring as an intermediate body in the conversion of starch into maltose and dextrose under the action of the ferments of the saliva and pancreatic juice.

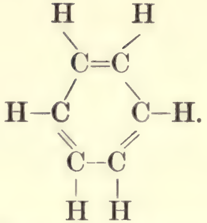
The Glucosides.

A group of substances occurs in plants which are decomposed by acids and ferments into one of the sugars, usually glucose or grape-sugar; and some other body. They are called *glucosides. Digitalin* and *salicin,* important on account of their medicinal properties, are of this class.

Salicin, $C_6H_{11}O_5OC_6H_4CH_2OH$, is a combination of grape-sugar, $C_6H_{12}O_6$, and oxybenzyl alcohol, $C_6H_4(OH)CH_2OH$.

THE AROMATIC GROUP.

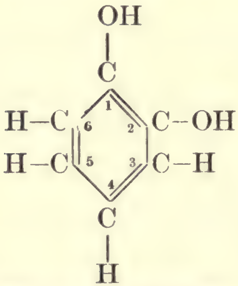
The **aromatic** or **ring compounds** are derived from *benzol* or *benzene.* The atoms in the molecule are arranged in a ring, the carbon atoms being united alternately by single and double bonds:



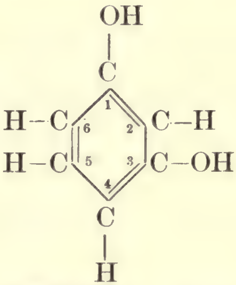
They are mostly obtained from the aromatic oils and resins. They differ from the fatty compounds in having a greater number of carbon atoms. They are mostly very stable, the benzene ring being broken with difficulty.

Benzol, benzene, C_6H_6, is obtained by fractional distillation from coal-tar. It is a light, limpid, strongly refracting liquid with an ethereal odor. It is very inflammable. It dissolves iodine, sulphur, phosphorus, fats, and other organic substances. It should not be confounded with the commercial *benzin*, used in pharmacy (Benzinum, U. S. P.), obtained from petroleum, and consisting of hydrocarbons of the fatty series.

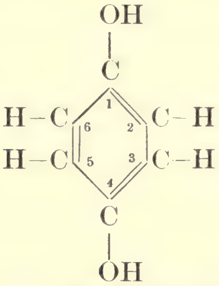
The derivatives of benzol: The hydrogen atoms may be replaced by elements or radicals. They are assumed to be equal, as only one class, *mono-derivatives*, is known ; but when two hydrogen atoms are replaced, *isomeric* modifications arise. Depending upon the position of the replacing element or radical, three compounds are formed, known as *ortho-*, *meta-*, and *para-*, thus :



Substitution of —OH in positions 1 and 2, ortho-dioxybenzol, pyrocatechin.



Substitution in 1 and 3, meta-dioxybenzol, resorcin.



Substitution in 1 and 4, paraoxybenzol, hydrochinon.

Additional compounds, formed by uniting directly an element to benzol, by breaking up the double bonds uniting the carbon atoms, exist. They are few and unimportant, $C_6H_6Cl_6$.

Amido derivatives: If the NH_2 group (amidogen) replaces the hydrogen of benzol, bodies are formed that resemble the *amines* of the fatty series.

Aniline, phenylamine, amino-benzol, $C_6H_5NH_2$, is a colorless, oily liquid. It is a strong base, uniting directly with acids and with certain salts. Its compounds form most of the artificial dyes.

The compound, **acetanilid**, or antifebrin, $C_6H_5NHCOCH_3$, is used in medicine as an antipyretic.

Phenols and Their Derivatives.

Phenols are aromatic hydrocarbons in which one or more hydrogen atoms have been replaced by hydroxyl –OH.

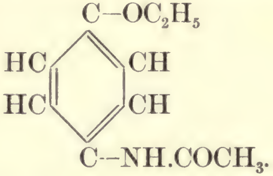
In their properties they are more like acids than alcohols, dissolving in alkalies, forming phenates. They also form ethers and other substitution-products.

Phenol, *carbolic acid*, C_6H_5OH, is obtained by fractional distillation from coal-tar.

The commercial carbolic acid is a colorless, crystalline substance, which gradually turns red when exposed to the air. It has a characteristic smell and burning taste. It is an antiseptic, and poisonous. It is soluble at 15° C. (59° F.) in 15 parts of water.

A mixture of phenols, chiefly guaiacol, $C_6H_4(OCH_3)OH$, and creasol, $C_6H_3(CH_3)OCH_3OH$, is used in medicine under the name of **creosote.**

The compound para-acetamido-ethyl-phenol, **phenacetin,** is used as an antipyretic,



The Aromatic Acids.

By replacing the hydrogen atom in benzol and its homologues by the *carboxyl* group –COOH, the aromatic acids are formed —*e. g.*,

C_6H_5COOH; Benzoic acid.

$C_6H_4(COOH)_2$. Phtaleic acid.

Benzoic acid, C_6H_5COOH, is a white crystalline compound, slightly soluble in water. It is used in medicine.

Hippuric acid, benzoylglycocol, $C_6H_5CO.NH.CH_2COOH$, occurs in the urine of herbivora normally and in the urine of carnivora after the ingestion of benzoic acid.

Tyrosin, para-oxylphenyl-amido-propionic acid, $HO.C_6H_4$-$C_2H_3NH_2COOH$, accompanies leucin (q. v.) as a product of the decomposition of proteids. It crystallizes in exceedingly fine needles, and is sparingly soluble in water.

Salicylic acid, or oxybenzoic acid, $HO.C_6H_4COOH$, occurs free in the flower of the Spiræa ulmaria; and its *methyl ester* in the oil of wintergreen.

It is a white, crystalline powder, odorless, and having a sweetish taste. It is soluble in 400 parts of cold water and readily soluble in chloroform.

Both salicylic acid and its salts are valuable medicines.

Gallic acid, trioxybenzoic acid, $(HO)_3C_6H_2COOH$, is crystalline, inodorous, and has a sourish taste. It is soluble in 100 parts of water.

Tannic acid, tannin, $C_{14}H_{10}O_9$. Pure tannin is digallic acid, formed from two molecules of gallic acid by the abstraction of water:

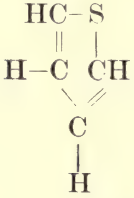
$$C_{14}H_{10}O_9 + H_2O = 2C_6H_2(OH_3)COOH.$$

It is a yellowish-white, uncrystallizable solid, soluble in 1 part of water.

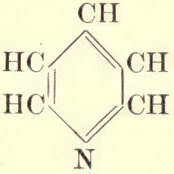
Both tannic and gallic acids occur in tea. The former is obtained chiefly from nut-galls. They are used in medicine as astringents.

OTHER RING COMPOUNDS.

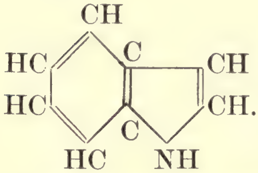
In a large number of complex organic bodies the atoms in the molecule are arranged in a ring, but some other atom than carbon enters into the formation of the ring—*e. g.:*

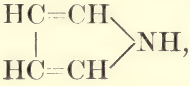


thiophen ;

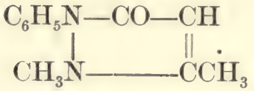


pyridin.

Indol,  , and methyl indol, or **skatol,** occur in the putrefactive decomposition of proteids, and are the substances which impart to fæces their unpleasant odor.

From the base *pyrrol,*  $\begin{matrix} HC=CH \\ | \\ HC=CH \end{matrix}\!>NH$, the drug **antipy-**

rin is derived,

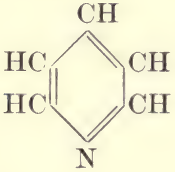


.

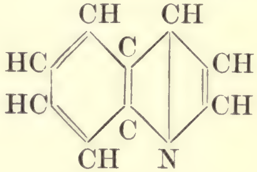
Vegetable alkaloids: Substances containing nitrogen and possessing basic characteristics found in plants were formerly classed under this heading.

A few of them have been found to belong to the amido-derivatives of the fatty series (v. Caffein). Most of them, however, belong to this class of ring compounds, and are derived from

pyridin,



; chinolin,



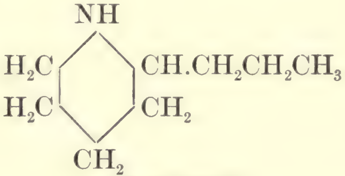
;

and isochinolin.

Most of the alkaloids have powerful medicinal properties.

In the *pyridin group* of alkaloids are piperine, derived from pepper; coneine, from hemlock; pilocarpine, from the leaves of jaborandi; nicotine, from tobacco; atropine, from belladonna; and cocaine, from cocoa leaves.

The graphic formula of *coneine* is:



Propylpiperidin.

In the *chinolin group* are quinine, cinchonine, from cinchona bark; and strychnine, from the nux vomica bean. In the *isochinolin group* are morphine, codeine, and apomorphine, from the juice of the poppy.

THE PROTEIDS.

A number of bodies of great complexity occur in the animal and vegetable kingdoms, the constitution of which is not exactly known. They are of great interest in physiological chemistry, forming the groundwork and essential part of all cell-protoplasm.

A **proteid body** is one containing nitrogen in a form suitable to the physiological needs of the body and yielding on decomposition amido-acid and nitrogenous bases (Chittenden).

All proteids contain N, C, H, O; almost all S; some P.

The proteid substances are very numerous, and are **classified** either by their chemical composition or by superficial differences, such as chemical reaction, solubility, etc.

There are three *main groups:*

1. Simple proteids.
2. Compound proteids.
3. Albuminoids or proteoids.

Stohmann and Langbein give *crystalline egg albumin* the formula:

$$C_{720}H_{1134}N_{218}S_5O_{248}.$$

Many of the proteids are **precipitated** by heat, alcohol, mineral acids, etc.—*i. e., coagulated.*

Reactions: 1. *Heated with Millon's reagent* (a solution of mercuric nitrate in nitric acid), proteids are colored violet-red. Same reaction is given by tyrosin.

2. On *boiling* with strong HNO_3, the solution turns yellow, which, on neutralization with ammonia, changes to an orange-yellow (xanthoproteic reaction).

3. Adding *caustic potash,* then a dilute copper sulphate solution, to proteid solutions: first a reddish-violet, then violet-blue, color is obtained (biuret reaction).

4. With *concentrated sulphuric acid* and *sugar* the albuminous bodies give a beautiful red coloration.

Simple Proteids.

1. **Albumins**: Soluble in water, weak acids and alkalies, and saturated solutions of NaCl and $MgSO_4$; coagulated by heat.

To this class belong serum-albumin, egg-albumin, lact-albumin, and vegetable albumin.

2. **Globulins**: Insoluble in water; soluble in 10 per cent. solution of NaCl; coagulated by heat.

Myosin, paraglobulin, and ptyloglobulin belong here.

3. **Albuminates** $\left\{\begin{array}{l}\textbf{acid}\\ \textbf{alkali}\end{array}\right\}$: Insoluble in water and dilute salt solutions; soluble in weak acids and alkalies; found in body as result of the digestion of proteid. The acid albuminate results from gastric digestion; the alkali, from pancreatic digestion.

4. **Proteoses** and **peptones** are found in the last stages of the digestion of proteids, and are also present in the toxic products of microörganisms in the body. Very soluble in water; insoluble in alcohol.

5. **Coagulated proteids**: Insoluble in water; soluble with difficulty in strong acids and alkalies.

Derived from other proteids: (*a*) By heat, change produced artificially; (*b*) changes produced in body (fibrin).

Compound Proteids.

1. **Chromo-proteids**, hæmoglobin, the coloring-material of blood.

2. **Gluco-proteids**: Proteids joined to carbohydrates:

(*a*) *Mucin*, present in nearly all mucus.

(*b*) *Mucoids*, present in connective tissue.

3. **Nucleo-proteids**: Made up of proteids combined with nuclein:

(*a*) *Para-nucleo-proteids;*

(*b*) *True nucleo-proteids.*

The essential proteids of milk are examples of para-nucleo-proteids.

4. **Gluco-nucleo-proteids.**

Albuminoids.

1. **Keratin**, found in skin, hair, etc.
2. **Neuro-keratin**, found in neuroglia-tissue.
3. **Collagen**, found in white connective tissue.
4. **Elastin**, found in yellow connective tissue.

PHYSICS.

Definition of physics: *Physics* is that branch of the natural sciences which especially treats of the *properties of terrestrial matter;* of the *forces* governing it, and of the *phenomena* pertaining to it. It treats of changes in the *state* of matter, while chemistry treats of changes in *identity*.

MATTER.

Definition of matter: *Matter* is anything which occupies space and whose existence is revealed to us by our senses. The *forces* governing it are those natural agencies which produce changes in its state; while by the term *phenomena* we simply mean the manifestations and changes produced by the action of these forces. The *properties* of a body are the different ways in which it presents itself to our senses.

Divisions of matter: All kinds of matter are divided into three kingdoms—*animal*, *vegetable*, and *mineral*. In many cases, however, the boundary-line is not clearly defined. Matter is also divided into two classes—viz., simple substances, or elements, and compound substances.

Simple substances or elements: These cannot, by any means known to us, be separated into differing component parts. At the present time we recognize some seventy of these elements, and many others have been proposed.

Compound substances: These are made up of the elements in varying proportions and arrangement:

A mass is the smallest amount of matter which we can appreciate by our senses. Theoretically, we regard this mass as being composed of a collection of molecules.

A molecule is the smallest quantity of any substance which can exist in a free state and still retain its characteristics. Still further, we suppose that each molecule consists of two or more atoms.

An atom is regarded as the ultimate unit of the elements; being physically indivisible and the smallest particle of matter which can exist, even in combination. Each atom of an element is identical with every other atom of the same element and differs from the atoms of all other elements.

States of matter: Matter exists in three states, which differ only in the degree of molecular aggregation. These states are the solid, liquid, and gaseous.

The *solid state* is that in which the molecules occupy a fixed relative position from which they cannot be moved without the use of more or less force. Bodies in this state tend to retain their form, as, for example, wood, stone, bricks, etc.

The *liquid state* is that in which the molecules do not occupy a fixed relative position, but can freely move past each other. As a consequence, a liquid readily assumes the shape of the vessel containing it. Examples of the liquid state are water, oil, mercury, etc.

The *gaseous state* is characterized by the fact that the molecules not only have far greater mobility than in the case of liquids, but are also repelled by each other, so that they are constantly struggling to make the gases occupy greater space. Examples of this state are air, oxygen, etc.

Crookes's vacuum is simply an ultra-gaseous state, in which the rarefaction of gas has been pushed to its utmost. It is a state in which *molecular*, as distinguished from *molar*, actions come into play. It is this state which causes the peculiar actions of the vane in a radiometer when exposed to heated or luminous surfaces. It is also by means of this state of vacuum that *x*-ray photography is rendered possible.

Properties of matter: The properties of matter are divided into two classes:

1. *Specific properties*, which pertain only to certain substances, or else only to certain states of these substances, and serve to distinguish them. These properties will be discussed with the states of matter which they serve to distinguish.

2. *General properties*, which are shared by all forms of matter. Among the more important are *impenetrability*, *extension*

or *magnitude*, *indestructibility*, *divisibility*, *porosity*, *compressibility*, *elasticity*, *mobility*, and *inertia*.

Impenetrability: The property by virtue of which no two portions of matter can occupy the same space at the same time. For example, if a stone be placed in a vessel of water, the level of the water rises proportionately to the size of the stone. Strictly speaking in a theoretical sense, this property applies only to atoms.

Extension or magnitude: The property by virtue of which every body occupies a limited portion of space, known as its *form* or *figure*. This is permanent in the case of solids; but varies with liquids and gases, according to the shape of the vessel containing them.

Indestructibility: The property by virtue of which matter cannot be destroyed, though it may change its state or identity. For example, water when boiled becomes converted into steam.

Divisibility: The property by virtue of which matter may be separated into distinct parts. For example, the tenth part of a grain of musk will for years fill a room with its odoriferous particles, yet at the end of that time will scarcely be diminished in weight. Blood is found to be composed of a colorless liquid, called serum, in which float red and white corpuscles. In man the diameter of one of these red corpuscles is less than $\frac{1}{3500}$th of an inch. The microscope reveals to us the fact that living organisms can dwell in the interior of one of these red cells. If we can imagine that these organisms have each their own system of bloodvessels, blood, and blood-corpuscles, we can only wonder at the infinitesimal size of each corpuscle. Experiment has failed to assign a limit to this property, but many facts in chemistry tend to show that it is reached when molecules have been divided into their component atoms.

Porosity: The property by virtue of which *interstices* or *pores* exist between the molecules of a body. There are two classes of these pores, varying according to their size:

Physical pores, which are so small that the surrounding molecules remain within the sphere of each other's attracting or repelling forces. The existence of these pores is not proved by our senses, but is assumed because of the general property of diminution of volume possessed by every body of matter. Contractions and expansions resulting from variations of temperature are due to the existence of these pores.

Sensible pores, or actual cavities, which are apparent to our senses, across which molecular forces cannot act. Such can be seen in pumice-stone, sponge, wood, etc. In the organic world these pores are the seat of absorption and exhalation. In consequence of the porosity of bodies, it is sometimes necessary to distinguish between the real and apparent volume of a body. The real volume is the amount of space actually occupied; while the apparent volume is the sum of the real volume and the total volume of the pores.

Compressibility: The property by virtue of which the volume of any body may be diminished by pressure. This property is both a consequence and a proof of the existence of porosity. Bodies differ greatly with regard to compressibility. Gases are the most compressible forms of matter, and their volume may, in some cases, be reduced to a few hundredths of the space normally occupied at ordinary temperatures. There is generally a limit beyond which continued pressure converts them to liquids. Solids are far less compressible. Of various solids, cloth, paper, wood, cork, etc., are among the most compressible; while metals are only slightly so. That metals are compressible to some extent is shown in the process of coining, when the metal receives an impression from the die. There is, in most cases, a limit beyond which increase of pressure either fractures solids or reduces them to powder. Liquids were for a long time regarded as incompressible; but it has now been shown by experiment that they can be compressed to a very slight degree.

Elasticity: The property by virtue of which bodies resume their original form or volume when the force which altered that volume ceases to act. This property may be developed in gases and liquids by pressure only; in solids by pressure, traction, flexion, or torsion. Gases and liquids are perfectly elastic, for, after undergoing a change in volume from the action of pressure, they regain exactly their original volume, in all cases, when the pressure is removed. Solids possess different degrees of elasticity, though never to the same extent as do liquids and gases. In all cases there is a limit beyond which they either break or become incapable of regaining their original volume. Within this *limit of elasticity* all solids are perfectly elastic. Rubber, glass, and ivory possess considerable elasticity; while lead, clay, and fats have scarcely any.

Mobility: The property by virtue of which the position of any body in space may be changed. Motion and rest may theoretically be either relative or absolute.

By the *relative* motion or rest of a body we mean its change of position with respect to surrounding bodies; by *absolute* motion or rest we mean the change or permanence of its position with respect to ideal fixed points in space. Thus a passenger on a train may be in a state of relative rest with respect to the train, but he is in a state of relative motion with respect to the objects, such as trees, past which the train rushes. These trees again enjoy merely a state of relative rest, for the earth which bears them is in a state of incessant relative motion. In short, absolute motion and rest are unknown to us.

Inertia: This is the purely negative though universal property of matter by virtue of which matter cannot of itself change its own state of motion or rest. If a body is at rest, it remains so until some force acts upon it: if it is in motion, this motion can only be changed by the application of some force. This property of inertia is expressed in Newton's first law of motion.

A body, when unsupported in mid-air, falls to the ground because it is acted on by the force of gravity, and not by virtue of any inherent property.

A billiard ball gently pushed does not move more and more slowly and finally stop because it has any preference for a state of rest, but because its motion is impeded by *friction*. Numerous phenomena may be explained by the inertia of matter. A string, which gently pulled would raise a weight, snaps at once if a sudden pull is exerted. A gentle push with the finger will move a door on its hinges, but a pistol bullet will perforate without moving it.

NATURAL FORCES ACTING ON MATTER.

The forces which act on matter are divided in three classes according as they act on atoms, molecules, or upon matter in general:

1. The force which acts on *atoms* is known as *atomic attraction.*

2. The forces acting on *molecules* are *cohesion*, *polarity*, *repulsion*, and *adhesion*.

3. The forces acting on *matter in general* are *gravity*, *heat*, *light*, *magnetism*, and *electricity*.

Atomic attraction or chemical affinity: This is the force which, by its action on atoms, serves to bind them together to form molecules. It varies according to circumstances, being opposed and diminished by heat.

Cohesion: This is the force which unites adjacent molecules of the same nature to form masses. It is strongly exerted in the solid state, less strongly in the liquid, and scarcely at all in the gaseous. It varies not only with the nature of bodies, but also with the arrangement of their molecules. For example, note the difference between the action of tempered and untempered steel, due to the difference produced in their molecular arrangement by the process of tempering. The strength of cohesion decreases as temperature increases. If in the case of solids it is once overcome, as through traction to the point of fracture, it is very difficult to bring the molecules close enough together again for it to become effective. *Welding*, by the application of heat, in the case of some metals restores this property. In large masses of liquids the force of cohesion is overcome by that of gravity, so that the liquids assume the shape of the vessels containing them; but in smaller masses cohesion gets the upper hand, and liquids assume the spheroidal form. This is seen in drops of dew on the leaves of plants, and also when a drop of liquid is placed on a solid which it does not moisten; as, for example, mercury upon wood.

Polarity: This is the force which acts on the molecules of certain bodies in such a way that a crystalline form is assumed in changing from the liquid to the solid state. By virtue of it, nearly all chemical substances assume special geometric forms and either increase or diminish the volume of their mass.

Repulsion, or the absence of cohesion, is the special force acting on gases. It is the tendency of their molecules to separate from each other as far as possible, and, in the exercise of it, they are continually hitting and repelling each other.

Adhesion: This is simply that form of cohesion which acts on molecules when they are combined in the form of masses, being exerted between the surfaces of bodies in contact. It can take place between solids, or between solids and liquids or gases. If two leaden bullets are cut so as to form two equal and brightly polished surfaces, and these surfaces are pressed and turned against each other till they are in the closest contact, they will adhere so strongly that a considerable force will be required to separate them.

The adhesion between solids and liquids is more powerful than that between solids alone. If two smoothly polished glass plates are coated with a thin layer of oil and pressed against each other, they will adhere strongly; but it will be found that, when pulled asunder, each plate is moistened by the oil, showing that in separating them their adhesion is overcome, but not the adhesion of the oil to them.

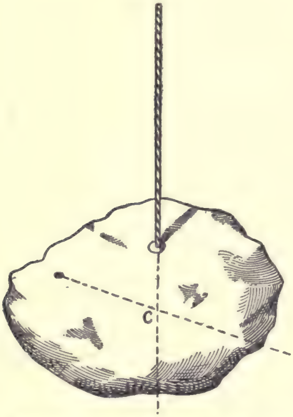
An example of adhesion between solids and gases may be seen when we immerse a glass or metal plate in water. Air-bubbles will be found to appear on the surface of the plate. As air cannot penetrate the pores of such a plate, it could not have come from it. The bubbles are solely due to a layer of air which covered the plate, *moistening* it like a liquid, and adhered so strongly that it was carried with it into the water.

GRAVITATION.

Universal attraction: This is the force by virtue of which the material particles of all bodies tend incessantly to approach each other. It is a mutual action exerted between all bodies at rest or in motion, no matter how great or how small the space between them, or whether this space be occupied or unoccupied. Sir Isaac Newton first formulated the law of this force—viz., *The attraction between two material particles is directly proportional to the product of their masses; and inversely proportional to the square of their distances asunder.* For example, if the distance between two masses be doubled, their relative attraction will be reduced to one-fourth of its former intensity. If one of two opposing masses be doubled in size, their relative attraction will merely be doubled.

Terrestrial gravitation: The tendency of any body to fall toward the earth's surface is merely a particular case of universal attraction, being due to the attraction between the earth and the body. This is known as *terrestrial gravitation.* At any point of the earth's surface the direction of gravity—that is, the line which a falling body describes—is called the *vertical line.* Vertical lines drawn at different points of the earth's surface converge very nearly to the earth's centre. A plane or line is said to be *horizontal* when it is perpendicular to the vertical line. The vertical line at any point of the globe is generally determined by the plumb line, which consists of a weight attached to the end of a string. The horizontal plane is also easily determined, since it coincides with the level surface of any liquid when in a state of equilibrium.

FIG. 2.

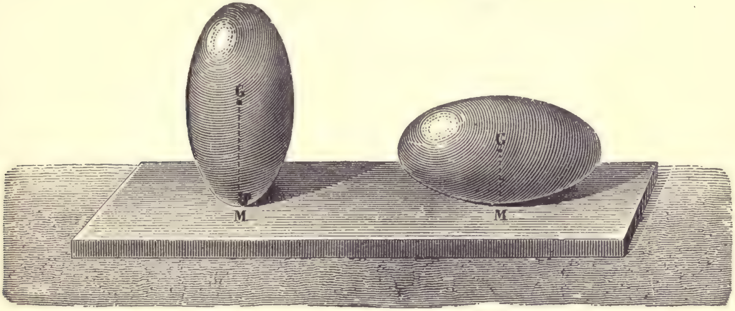


Experimental determination of centre of gravity (Deschanel).

Centre of gravity: The centre of gravity of a body is that fixed point through which passes, irrespective of the position of the body, the resultant of the attracting forces between the earth and its several molecules. It may be within or without the body, according to its form; and can, in many cases, be easily determined. In a sphere of uniform density it is, of course, at the centre. In order to find experimentally the centre of gravity of a body, it is suspended by a string in two different positions, as shown in Fig. 2. The point *C*, where the directions of the string in the two experiments intersect each other, is the centre of gravity required.

Equilibrium : Since the action of gravity upon a body reduces itself to a single vertical force directed through its centre of gravity toward the earth's centre, equilibrium, or a *state of balance*, only results when the force of gravity is balanced by the resultant of all other forces acting on the body at its centre of gravity. If only one point of a body is fixed, it will be in equilibrium only when its centre of gravity lies in a vertical line drawn through this fixed point. If more than two points be fixed, equilibrium will exist if a vertical line through the centre of gravity pass through the polygon formed by joining the points of support. As the centre of gravity of a body constantly tends to occupy the lowest possible position, we can recognize three different states of equilibrium, dependent on the relative position of this centre.

FIG. 3. FIG. 4.



Unstable equilibrium. Stable equilibrium.
(Deschanel.)

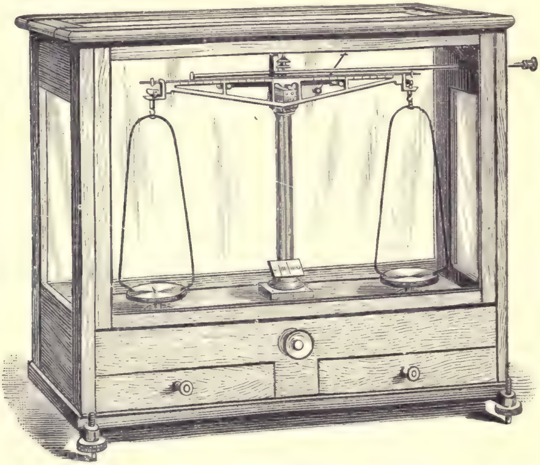
States of equilibrium : Equilibrium may be stable, unstable, or neutral.

Stable equilibrium exists if a body, after its equilibrium has been slightly disturbed, tends to return to its former position. This happens when the centre of gravity is so placed that it is raised by the slightest alteration in the position of the body ; as would happen to an egg lying on its side, as in Fig. 4.

Unstable equilibrium, as indicated by the egg in Fig. 3, exists if a body, after the slightest disturbance of its equilibrium, tends to depart still more from its original position. This happens when the centre of gravity is vertically above the point of support, or higher than it would be in any adjacent position of the body.

Neutral equilibrium, as indicated by a perfect sphere upon a horizontal plane, exists if a body is always in equilibrium, no matter what its position: that is, alteration of its position does not affect the relative position of the centre of gravity.

FIG. 5.



Chemical balance (Draper).

The balance: From an application of the principles of gravity we get the *balance*, an instrument for determining the relative weights or masses of bodies. In its simplest form, a balance consists of a beam (Fig. 5), having at its centre a fulcrum whose sharp edge rests on two agate supports. To the extremities of the arms of the beam are attached scale-pans. A needle is fixed to the beam and moves over a graduated arc, and when the beam is horizontal the needle points to the zero mark of the arc. By means of it, bodies are weighed and the results expressed in units of weight.

The *conditions which must be satisfied* by a balance are:

(1) The two arms of the beam must be equal in length;

(2) The balance must be in equilibrium when the scales are empty;

(3) When the beam is horizontal, the centre of gravity should be in the same vertical line with, and a little below, the edge of the fulcrum.

Laws of falling bodies: Since bodies fall to the ground because of the earth's attraction on each of their molecules, we might suppose that all bodies, heavy or light, would fall with equal rapidity. In practice, however, we know that a coin falls much faster than a feather. This difference in speed has been found to be due to the resistance of the air; for in a vacuum all bodies fall with equal rapidity. To prove this, put a feather and a coin in a long glass tube and produce a vacuum in it. It will then be seen that the coin and feather fall with equal rapidity.

Uniform acceleration: The fall of a heavy body illustrates the second law of motion. Gravitation continually acts on the falling body and accelerates its speed. If its velocity at the end of the first second were x, at the end of the next second it would be $x + x$, and at the end of the third, $x + x + x$. Such a motion is uniformly accelerated.

FORCE AND MOTION.

Force is revealed to us by the changes it produces or tends to produce in the motion of matter. As we have already seen, the terms motion and rest are merely relative. When a force produces acceleration of motion, or when it maintains motion unchanged in opposition to resistance, it is said to do *work*.

Energy is the capacity of any agent for doing work, and is measured by the amount of work it can accomplish. It is divided in two classes—potential and kinetic.

Potential energy, or energy of position, is possessed by a mass in consequence of work done upon it.

Kinetic energy, or energy of motion, is that possessed by a body in consequence of its velocity.

Velocity refers to the space traversed by a body in a given time. It is called *uniform* if the rate of speed remains the same; *variable*, if it changes.

Momentum is equivalent to quantity of motion, and depends on both velocity and mass. In the case of any moving body, the momentum is equivalent to the product of the velocity by the mass. As a consequence, a small body moving very quickly may have more momentum than a much larger body moving much more slowly.

To obtain proper measures of all these manifestations of force, we have been compelled to establish certain *arbitrary units* of time, space, and mass.

Units: *Unit of time* = The second, which is $\frac{1}{86400}$th part of the average or mean solar day.

Unit of length or distance = The foot.

Unit of mass = The pound.

From these primary units we have formulated various *secondary ones*, such as:

Unit of area = A square, one side of which is the unit of length = square foot.

Unit of volume = A cube, one edge of which is the unit of length = cubic foot.

Unit of velocity = A speed of 1 foot per second.

Unit of work = The force required to raise one pound through a distance of 1 foot.

Unit of force = The force required to impart the unit of velocity to the unit of mass in the unit of time.

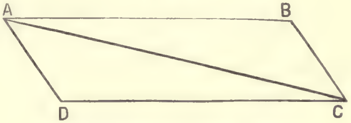
Laws of motion: The laws governing the manifestations of force in motion, as formulated by Newton, are three in number:

First law: Every body will continue indefinitely in its state of rest or of motion in a straight line at a uniform velocity unless acted upon by some external force. As we have already said, this law depends on the property of inertia, which, were it not for the action of friction, would produce perpetual motion.

Second law: If any number of forces act together upon a body, either in motion or at rest, each force has the same effect in producing motion as it would have if it acted singly.

The several forces acting in any case are called the *components*, while the effect of their combined action is called the *resultant force.* This resultant force may be demonstrated by employing the geometrical parallelogram of forces (Fig. 6). Let *B* and *D* be two forces acting on *A* along the lines *B A* and *D A*. On these two sides, *B A* and *D A*, taken as expressing the relative magnitudes of these two forces, construct the parallelogram *A B C D*. The diagonal *C A* will represent in relative magnitude and in direction the resultant of the action of the component force *B* and *C* on *A*.

Fig. 6.



Parallelogram of forces (Draper).

Third law: Action and reaction are always equal and opposite. That is, the mutual actions of two bodies on each other, whether they be at rest or in motion, are always forces equal in amount, but opposite in direction. The earth attracts the moon, and the moon attracts the earth.

MACHINES.

A machine is an apparatus for the conversion of energy into a convenient form. It does not create new energy. The universal law of machines is that what is gained in force is lost in space, and *vice versa;* that the power multiplied by its space of descent is always equal to the weight multiplied by its space of ascent. As a matter of fact, in the use of machines a certain amount of energy is lost, or rather expended, in overcoming friction, being transformed, as we shall see later, into heat. There are six simple machines upon whose principles all machinery is constructed. They are the *lever*, *screw*, *inclined plane*, *wedge*, *pulley*, and *wheel and axle.*

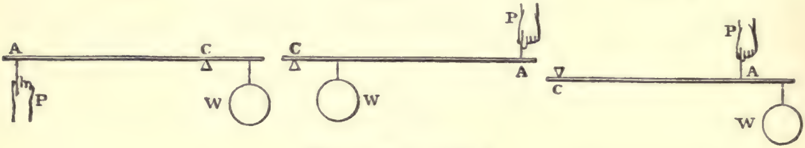
The lever: This is the name given to any bar, straight or curved, which rests on a fixed point or edge of support, known as the *fulcrum.* The forces acting on the lever are the *weight*, or *resistance*, and the *power*. The distances from the fulcrum to the points of application of the weight and power are known as the *arms* of the lever. The weight and power are inversely to each other as the length of their arms. Levers are divided into three orders, according to the position of the fulcrum, *C*, with respect to the points of application of the weight, *W*, and the power, *P*.

First order: *C* is between *P* and *W*, as in Fig. 7; or as in the common steelyard.

Second order: *W* is between *C* and *P*, as in Fig. 8; or as in the wheelbarrow. Power is gained, but time is lost.

Third order: *P* is between *C* and *W*, as in Fig. 9; or as in the treadle of a sewing-machine. Power is lost, but time is gained.

Fig. 7. Fig. 8 Fig. 9.

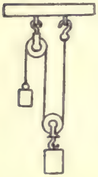


Three orders of levers.

Wheel and axle: The wheel and axle may be regarded as an endless lever, the radii of the wheel and axle being its arms.

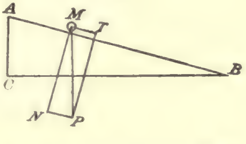
Pulley: A pulley, when fixed so that it can only turn about a fixed axis, confers no mechanical advantage, and may be regarded as an endless lever of the first order whose arms are equal. If two pulleys are used, as in Fig. 10, the lower one may be regarded as an endless lever of the second order, in which the arm of the power is the diameter of the pulley and the arm of the weight is half the diameter. If the weight rises 2 inches, the power descends 4 inches, and mechanical advantage is gained.

Fig. 10.



Inclined plane: Let *A B* in Fig. 11 be an inclined plane. Then *A C*, drawn vertically, is its height. *B C*, drawn horizontally, is its *base*, and *A B* its *length*. The force of gravity upon a heavy body, *M*, may be represented by the vertical *M P*, which may be resolved by a parallelogram of forces into two components, *M T*, parallel to and *M N* perpendicular to *A B*. A force equal and opposite to *M T* will prevent the body from slipping down; hence the power is to the weight as *M T*:

Fig. 11.



MP. The two right-angle triangles ABC and MTP are similar, as the angles M and A are equal; hence, $MT : MP :: AC : AB$—that is, as the height to the length of the plane. Therefore, we can say power : weight : : height of plane : length of plane. If the force acted parallel to the base, instead of the length of the plane, the formula would be power : weight : : height of plane : base of plane.

Wedge: This is an example of the inclined plane, but its practical action is very greatly affected by friction.

Screw: This also is an application of the inclined plane. The length of one turn of the thread is the length; the distance between two successive turns, measured parallel to the axis of the screw, is the height; and the circumference of the screw is the base of a corresponding inclined plane.

Conservation of energy: We have seen how energy may be transformed into work. But though this can be done, the total amount of energy cannot be diminished nor increased in any way. This great natural law is known as the conservation of energy. The energy which is lost in machines by friction is converted into heat; but is not really lost, as this amount of heat can accomplish work of other kinds, and so on.

Friction: Friction, or opposition to motion, results from the fact that bodies are never perfectly smooth. When one body moves over the surface of another, the elevations of one sink into the depressions of the other, like the teeth of wheels, and thus offer a certain resistance to motion, called friction.

Sliding friction occurs when one body glides over another.

Rolling friction occurs when one body rolls over another, and is less than the former.

Friction is directly proportional to the pressure of the two surfaces against each other; but is independent of the extent of the surfaces in contact if the pressure remains the same. It is diminished by polishing or greasing, but is increased by heat.

SOLIDS.

Properties of solids: In addition to the general properties of matter common to it in all forms, solids have, as properties peculiar to them, *solidity; elasticity*, as developed by traction, torsion, or flexion; *tenacity; ductility;* and *hardness.*

Solidity: This is that property of the solid state by virtue of which solids tend to retain their form or shape.

Tenacity: This is the resistance which a body offers to the total separation of its parts. It varies both with different substances and with their shape. A hollow cylinder has greater tenacity than a solid one of the same weight. A wire cable is stronger than an iron rod of the same length and weight. According to the manner in which the external force acts, we have *tenacity* in the ordinary sense, or resistance to traction; *relative tenacity*, or resistance to fracture; *reactive tenacity*, or resistance to crushing, etc.

Elasticity of torsion, traction or flexion: By these terms are meant those manifestations of the general properties of elasticity which can only be developed in solids, and whose character is indicated by the special term applied. They follow the general laws of elasticity in that their particles tend to regain their original position. There is, too, a *limit of elasticity* beyond which continuance of the force produces an incapacity of the substance for regaining its former shape and position.

Ductility: This is the property by virtue of which many kinds of solids change their form on the application of traction or pressure. The degree varies in different substances, and is probably due to a certain amount of fluidity. Clay and wax need very little force to cause them to change their shape, while a great deal is required to draw out metal into the form of wire.

Malleability: This is simply a form of ductility which is exhibited by hammering. Gold, the most malleable metal, has been beaten into leaves $\frac{1}{300000}$th of an inch in thickness; while platinum, the most ductile metal, has been drawn into wire only $\frac{3}{100000}$th of an inch thick.

Hardness: This is the resistance which bodies offer to being scratched or worn by other bodies. It is merely a relative property; as a body which is hard in reference to one substance may be soft in reference to others. The diamond, the hardest of all bodies, scratches everything, but is not scratched by anything. The *scale* of hardness usually adopted is, beginning at the softest:

Talc, Rock-salt, Calcspar,
Fluorspar, Apotite, Felspar,
Quartz, Topaz, Corundum, Diamond.

The hardness of many bodies, more especially steel, can be changed by the application of heat.

Tempering, or sudden cooling after being raised to a high temperature, makes such bodies very hard and brittle.

Annealing, or slow and gradual cooling after heating, makes them softer and more flexible.

LIQUIDS.

Science of hydrostatics: This treats of the conditions of the equilibrium of liquids and of the pressures they exert. We have already seen that liquids are substances whose molecules are displaced by the slightest effort. This property of *fluidity* is not perfect, however, as the particles tend to adhere slightly, a property known as *viscosity*. Liquids differ as to their degree of viscosity, those which possess it in the highest degree being termed *viscous;* for example, molasses. Liquid differ from gases in being somewhat less fluid, comparatively inexpansible, and almost entirely incompressible. Experiments have shown that the density of salt water at the depth of a mile is increased about only $\frac{1}{300}$th. They have also shown that every liquid after compression, no matter how great, at once regains its original volume when the pressure is removed, indicating that liquids are perfectly elastic.

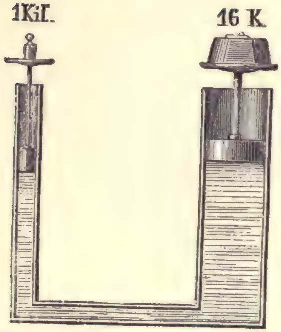
Equality of pressure—Pascal's law: Pascal, by considering liquids as perfectly fluid and assuming them to be uninfluenced by the action of gravity, formulated the following law for their action under pressure:

Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force on all equal surfaces, and in a direction at right angles to those surfaces.

For example, imagine a vessel with several cylindrical apertures of equal size, closed by movable pistons, and filled with fluid. Upon one of the pistons place a weight, say of ten pounds. Then a pressure of ten pounds will be transmitted against the face of every other piston. If the area of one piston be only one-fourth that of each of the other pistons, and a weight of ten pounds be placed on it, a pressure four times as great—*i. e.*, forty pounds—would be exerted against each of the other pistons, the area of each being four times that of the first one.

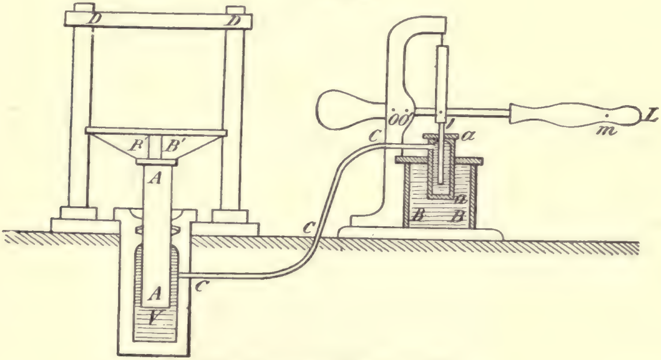
This can be approximately verified by taking a vessel, such as is indicated in Fig. 12, consisting of two cylinders of unequal diameter, joined by a connecting tube, and filled with water, having a piston in each. If the sectional area of the larger cylinder be sixteen times that of the smaller cylinder, it will be found that a weight of one kilogram on the smaller piston will support a weight of sixteen kilograms on the larger one.

Fig. 12.



Principle of the hydraulic press.

Fig. 13.



Bramah press (Deschanel).

The hydraulic press: This is an important application of this principle, and serves as a means for producing enormous pressures. It consists (Fig. 13) of a cylinder, with very strong, thick sides, in which there is a cast-iron ram, *A*, working through a water-tight collar. By means of a pipe, *C*, the cylinder communicates with a small force-pump, which works by means of a lever, *L*. When the piston, *I*, of the force-pump rises, water flows into it; but when the piston descends, the water is driven through the tube into *V*. By means of the lever an additional advantage is obtained. If the sectional area of *A* is one hundred times that of *I*, and if, on the lever, the distance of the point *m* from the fulcrum is five times that from the fulcrum to the piston, a pressure of 10 pounds on *m* will act on *I* with a pressure of 50 pounds, and on *A* with a pressure of 5000 pounds ($10 \times 5 \times 100 = 5000$).

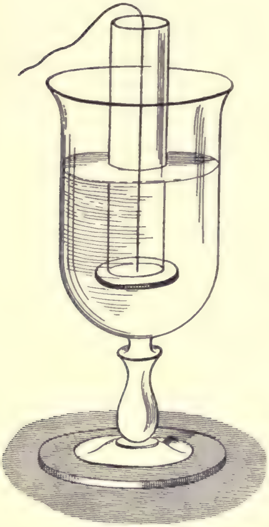
Vertical downward pressure due to gravity: If we suppose that any given liquid at rest in a vessel be divided into horizontal layers of the same density, it is evident that each layer supports the weight of those above it. Gravity thus produces internal pressures which vary at different points, and are subject to the following laws:

1. The pressure in each layer of the liquid is proportional to the depth.
2. With different liquids and the same depth, the pressure is proportional to the density of the liquids.
3. The pressure is the same at all points of the same horizontal layer.

From a consideration of these laws and those of Pascal, it may be seen that the pressure exerted on any portion of the sides or bottom of a vessel containing fluid is equal to that exerted by a column of the same liquid, having for its base this portion of the sides or bottom, and for its height the vertical distance from the centre of gravity of this portion to the surface level of the liquid.

Vertical upward pressure: The vertical downward pressure exerted by the upper layers of a liquid on the lower ones causes them to exert an equal upward reaction, known as *buoyancy*. It is very sensible if the hand be plunged in a dense liquid, such as mercury. This upward pressure is governed by the same laws as downward pressure. In Fig. 14 a large open glass cylinder is fitted with a thin card, held in place at its lower end by a string, and plunged in a vessel of water. The upward pressure of the water keeps the card in position till enough water is poured into the tube to bring its level up to that of the water outside. Consequently the upward pressure on the card is equal to the pressure of a column of water having the area of the card for a base, and a height equal to the distance of the card from the upper surface of the liquid.

FIG. 14.



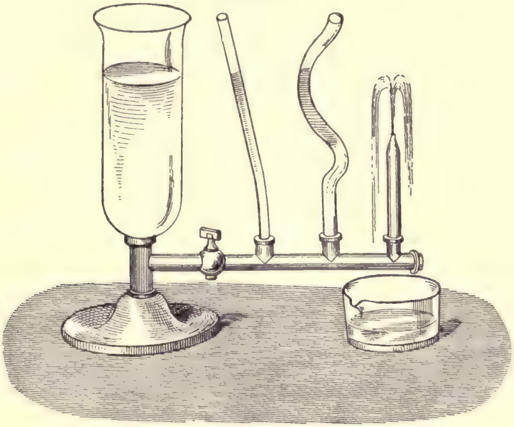
Upward pressure (Deschanel).

Pressure is independent of the shape of the vessel and of the quantity of liquid, but depends on the depth and the density.

Equilibrium of liquids: The surface of any liquid in a state of rest is level, and every molecule of its mass is subject in every direction to equal and contrary pressures. If the liquid is contained in two or more different but communicating vessels, as in Fig. 15, it will not come to a state of equilibrium till the surface is at the same level in them all. The old saying, that "Water will find its own level," depends on this. It is this force which causes water to flow from an Artesian well or, in our own homes, from the water pipe which leads from a reservoir situated at a greater elevation. It is independent of the size or shape of the vessel. The water-level is a familiar practical application of this property (Fig. 16).

Equilibrium of different liquids in communicating vessels: When two liquids of different densities, and which cannot mix, are contained in communicating vessels, they will only be in equilibrium when, in addition to satisfying the preceding principles, the heights of the two columns above the level of their point of contact are in the inverse ratio of their densities. This may be shown by pouring mercury into a glass tube bent

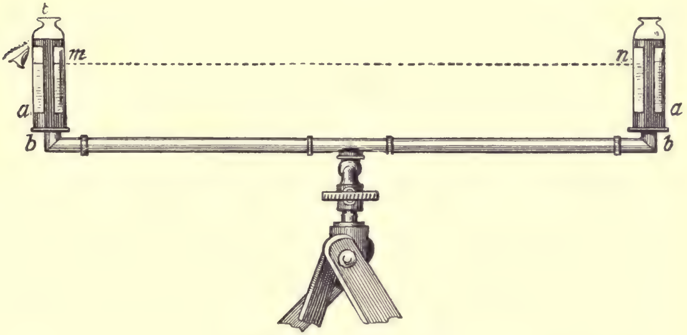
FIG. 15.



Vessels in communication (Deschanel).

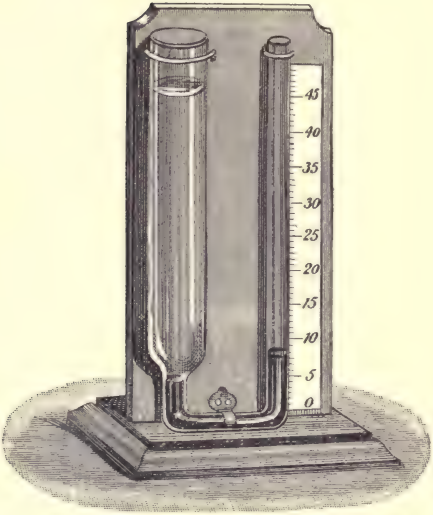
in the shape of the letter U (Fig. 17). Pour water into one leg of the tube, and we can see that its column presses on the mercury and lowers its level in one tube, but raises it in the other. If we imagine a horizontal plane passing through their point of contact, we will find that the column of water extends about thirteen and one-half times as far above it as does the mercury.

FIG. 16.



Water-level (Deschanel).

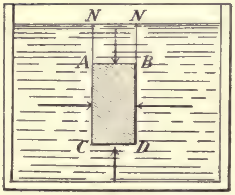
FIG. 17.



Equilibrium of two fluids in communicating vessels (Deschanel).

As the density of mercury is about thirteen and one-half times that of water, the heights of the columns are inversely as the densities.

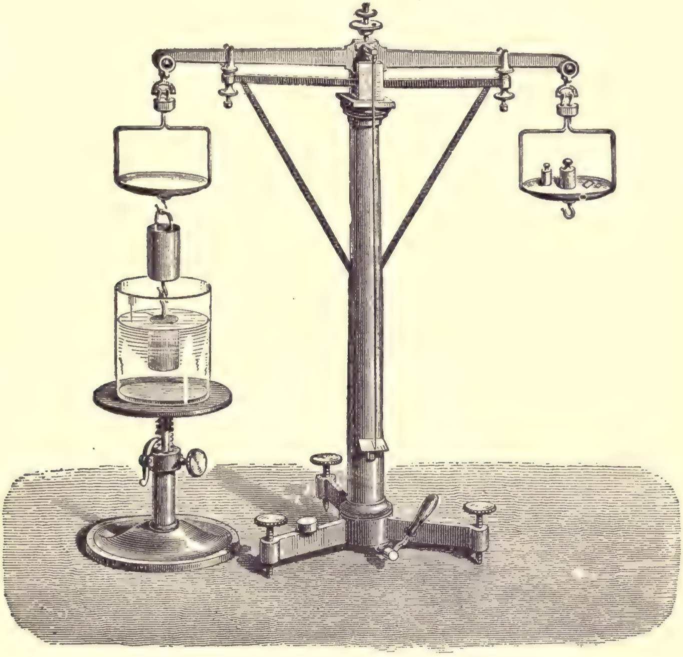
FIG. 18.



Principle of Archimedes (Deschanel).

Bodies immersed in liquids: When a body is immersed in a liquid, its surface is subject to pressure in all directions. If these pressures be decomposed into their horizontal and vertical constituents, it will be found that the first are in equilibrium. By experiment with a rectangular body immersed in water (Fig. 18), it may be seen that the upward pressure on the surface *C D*—equivalent to that exerted by a column of water *N D* in height, with the surface *C D* for a base—exceeds the downward pressure on the surface *A B*—equivalent to that exerted by a column of water *N A* in height with the surface *A B* for a base—by an amount equal to that exerted by a column of water *C A* in height with either of the equal surfaces *A B* or *C D* for a base. In other words, this difference is equal to the pressure exerted by the weight of the volume of liquid displaced by an immersed body. As gravity acts at all times and under all circumstances, this experiment shows that a body immersed in a liquid loses in weight an amount equal to the weight of the volume of liquid it displaces.

FIG. 19.



Experimental verification of principle of Archimedes.

Principle of Archimedes: This principle of the loss of weight of immersed bodies is named after Archimedes, its discoverer. It is the basis of the theories of immersed or floating bodies;

and may be demonstrated experimentally by fastening a cord to a heavy stone and then appreciating with the finger the apparent loss of weight when the stone is lowered into water.

Hydrostatic balance : This gives accurate proof of the principle of Archimedes. It consists (Fig. 19) of an ordinary balance, which has attached to one scale-pan a hollow cylinder closed at the bottom ; and hanging from this a solid cylinder which will exactly fill the hollow one. Therefore, the volume of one equals the capacity of the other. Being careful that the hollow one is empty, balance them both by weights in the opposite scale-pan. Then so place a vessel of water that the solid one is totally immersed. The scale-pan holding the weights will then drop, showing that weight has been lost. Fill the hollow cylinder with water and the indicating-needle will show that equilibrium has again been restored, proving that the weight lost by immersion of the solid cylinder was exactly equivalent to the weight of the water contained in the hollow one, or, in other words, to that of the volume of water displaced.

Floating : If the weight of any body is less than that of an equal volume of the liquid in which it is placed, it will only sink till it has displaced a volume of the liquid equal to its own weight. It will then remain at rest or float. Its centre of gravity will gain the same vertical line as that of the centre of the liquid displaced.

SPECIFIC GRAVITY.

The specific gravity or **comparative density** of equal volumes of different substances is ascertained by the application of this principle of the loss of weight of immersed bodies.

The specific gravity of any substance is expressed arbitrarily by figures, denoting the relation of its weight in the case of solids and liquids to that of an equal volume of distilled water at a certain temperature ; or, in the case of gases, to that of an equal volume of air or hydrogen, both being at a temperature of 0° C., and under a pressure of 760 mm. In this country and England the distilled water is at a temperature of 60° F., while in Germany and France it is at 4° C.

There are three methods in common use for determining the specific gravities of solids and liquids:

1. Method of the hydrostatic balance;
2. Method of the hydrometer;
3. Method of the specific gravity flask.

Method of the hydrostatic balance: *Solids:* The solid is first weighed in air and then in water. As the loss of weight in water is equivalent to the weight of an equal volume of water, we can get the specific gravity by dividing the weight in air by the loss of weight in water.

Example:

Weight of a body in air = 293.7 ounces.
Weight in water = 180.1 "
Difference or weight of an equal volume of water = 113.6 "

$$\text{Hence, specific gravity} = \frac{293.7}{113.6} = 2.59.$$

When substances are lighter than water, a weight is generally used as a sinker. The substance is first weighed in air; then the sinker is weighed in both air and water, and then the substance and sinker are weighed together--first in air and then in water. The specific gravity can then be calculated as follows:

Example:

A piece of wax weighed in air = 133.7

The wax and sinker weighed in air = 187.7
The wax and sinker weighed in water = 38.8
Weight of volume of water equal to that of wax and sinker = 148.9

Weight of sinker in air = 54.
Weight of sinker in water = 44.4
Weight of an equal volume of water = 9.6 9.6
Weight of volume of water equal to that of wax alone = 139.3

$$\therefore \text{Specific gravity of wax} = \frac{133.7}{139.3} = 0.9598.$$

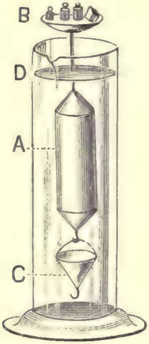
If the substance is soluble in water, use some other liquid of known specific gravity, in which it is not soluble. Ascertain the specific gravity of the substance as compared to the liquid used, and multiply by the specific gravity of the liquid. The result will be the specific gravity of the substance.

Liquids: Suspend from the pan of the balance a weight of some metal on which the liquid cannot act—for example, a ball of platinum. Weigh this successively in air, in distilled water, and in the liquid. The loss of weight in each fluid represents the weights of equal volumes of the two fluids. The specific gravity will be the result obtained by dividing the loss of weight in the fluid being tested by the loss of weight in water.

Method of the hydrometer: The hydrometers used for determining the specific gravity of solids differ somewhat in construction from those used for liquids; but the principle is the same. Nicholson's is used for solids, while Fahrenheit's is used for liquids.

Nicholson's hydrometer: This consists of a hollow metal cylinder, to which is attached a cone loaded with lead (Fig. 20). At the top is a stem terminating in a scale-pan, and on the stem is marked a standard point. The apparatus is placed in water, and weights are placed on the pan till it sinks to the mark on the stem. The weights are then removed, the substance to be tested is placed in the pan, and weights again added till the hydrometer sinks to the mark. The difference between the weights added in the two instances is the weight of the substance in air. The solid is then placed on the upper surface of the loaded cone, and fastened there by a small wire cage if it floats in water, the weights in the upper pan being left untouched. As the substance has lost by immersion a part of its weight, the hydrometer no longer sinks to the mark. The amount of weight which now must be added to immerse it again to the standard mark represents the weight of the volume of water displaced. The specific gravity can be ascertained as before.

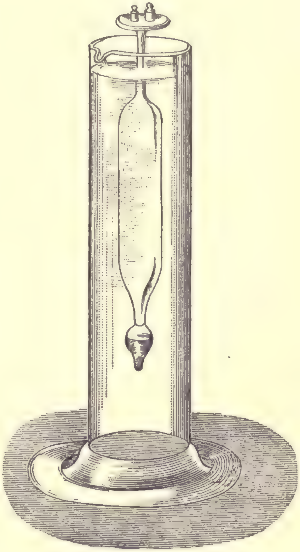
FIG. 20.



Nicholson's hydrometer (Draper).

Fahrenheit's hydrometer: This resembles Nicholson's, but is made of glass, so that it may be used in all liquids (Fig. 21). At its lower extremity, instead of a pan, it has a small bulb loaded with mercury, while there is a standard mark on the stem supporting the scale-pan. The instrument is first weighed in air; it is then placed in water and weights added till it sinks to the mark. The weight of the hydrometer in air plus the weights added represents the weight of the volume of water displaced. In the same way we can get the weight of an equal volume of the liquid to be tested. Dividing the latter by the former gives the specific gravity.

FIG. 21.



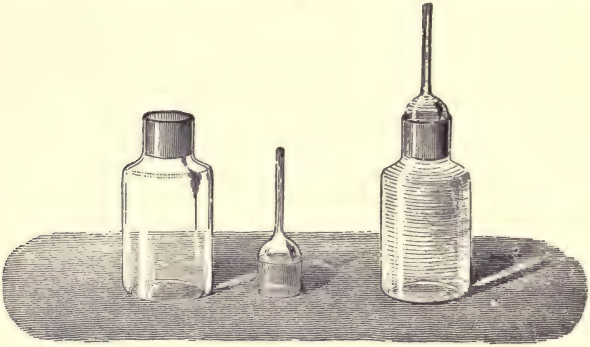
Fahrenheit's hydrometer (Deschanel).

Method of the specific-gravity bottle: As with hydrometers, different forms of specific-gravity bottles are used in the case of solids and of liquids.

In the case of *solids*, the bottle is chiefly used for determining the specific gravity of powders (Fig. 22). The weights of the powder and of the bottle when full of water are both accurately determined. The bottle is then emptied, the powder placed in it, and water added till it is completely filled, when it is weighed. If the third of these results be subtracted from the sum of the first two, the remainder will be the weight of the water displaced. The weight of the solid or powder in air divided by this remainder is the specific gravity desired.

For *liquids*, a bottle of special construction is used. It consists of a cylindrical bottle, to the neck of which is fused a capillary tube, and to this again a wider tube closed by a stopper. The bottle is first weighed when empty, and then when successively filled with water and with the liquid to be tested, to a mark on the capillary stem. Subtracting the weight of the bottle when empty from its weight when filled with the two liquids gives the weight of equal volumes of water and of the other liquid. Dividing the latter by the former gives the specific gravity.

FIG. 22.



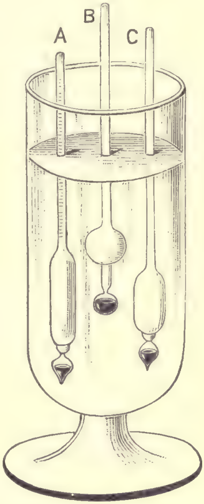
Specific-gravity flasks for solids.

Hydrometers: There are two varieties of hydrometers, those of *constant immersion but variable weight*, such as Nicholson's and Fahrenheit's; and those of *variable immersion but constant weight*, which have a fixed weight attached to them and are immersed to a variable extent. A type of this latter class is Beaumé's hydrometer. The lactometer, urinometer, alcoholometer, etc., are among the numerous varieties. Hydrometers do not give as accurate results as the other methods of ascertaining specific gravity, but they are very convenient.

Hydrometers of variable immersion: The instruments are usually made of glass and of the forms represented in Fig. 23. The lower end is weighted with mercury to immerse the instrument and keep it upright, while the cylindrical stem is graduated. As the instrument sinks the deeper, the less the specific gravity of the liquid in which it is immersed; the graduations can be so arranged on the stem that the reading at the level of the liquid will indicate its specific gravity.

Beaume's hydrometer: In these instruments the divisions of the scale on the stem are equidistant. If the instrument is

Fig. 23.



Forms of hydrometers (Draper).

to be used in liquids of greater specific gravity than water, it is so weighted that it will sink in water nearly to the top of its stem. This point is marked zero, and the point to which it will sink in a solution of 15 parts of salt in 85 of water is marked 15. The interval is divided into 15 degrees and the graduation continued to the bottom of the stem. If for liquids lighter than water, it is so weighted that the zero-mark, the point to which it sinks in a solution of 10 parts of salt to 90 of water, will be near the bottom of the stem, while the point to which it sinks in water is marked 10, and the rest of the scale completed as before. Beaumé's instruments give only conventional readings, which must be converted into specific gravities; but the lactometer, etc., are so marked that they give direct readings in specific gravity.

Specific gravity of gases: The specific gravity of a gas is, as has been said, the ratio of the weight of a certain volume of the gas to that of an equal volume of air or hydrogen; both the gas and the air or hydrogen being at 0° C., and under a pressure of 760 mm. There are two methods of finding this:

First method: That of directly weighing the gases: Take a large metallic globe with a stopcock, exhaust the air from it and weigh it. Then fill it with air or hydrogen, from which the moisture has been carefully removed, and weigh it again. The difference in weights is equal to the weight of the volume of air or hydrogen. By carrying out the same method with the gas to be tested, we can get the weight of an equal volume. It is difficult to make these determinations at the same temperature and pressure, so all the weights are reduced to zero and the normal pressure of 760 mm. By dividing the weight of the gas tested by the weight of the air or hydrogen, we get the specific gravity.

Second method: Depending on Avogadro's law, that under the same pressure, and at the same temperature, equal volumes of all gases contain the same number of molecules, we find that the relative densities of gases are directly as their molecular weights. Hydrogen is usually taken as the unit, because it gives the specific gravities of most gases in whole numbers, while when using air as the unit we get fractions. As we consider the atomic weight of hydrogen as unity or 1, and as the molecule of hydrogen has two atoms, its molecular weight is 2. The specific gravity of any gas, as compared to hydrogen, is one-half its molecular weight. *Example:* Molecular weight of oxygen is 32, and that of hydrogen is 2. Consequently the specific gravity $= \frac{32}{2} = 16$. Taking air as the unit, the specific gravity of oxygen $= 1.1057$.

CAPILLARITY. OSMOSIS. DIFFUSION.

Capillary phenomena: When solid bodies are placed in contact with liquids certain phenomena are observed, called *capillary phenomena*, because they are most marked when tubes of very small calibre are used. The force producing them is called *capillarity* or *capillary attraction*. All these phenomena may be referred to the relation of the attraction of the liquid molecules for each other, and to the attraction between these molecules and solid bodies. If we thrust a rod into a liquid which wets it—as a glass rod into water—the liquid, contrary to all the laws of gravity, is raised upward on the sides of the rod. If, on the contrary, the liquid is one which does not wet the rod—for example, mercury—it is depressed against its sides, and assumes a convex shape. If, instead of a rod, we use a tube, the surface of the liquid, both within and without it, will assume a similar concave or convex shape, according as the liquid does or does not wet the tube (Figs. 24 and 25). This shape within the tube is known as a *concave* or *convex meniscus*, as the case may be. The liquid also, depending on whether it does or does not wet the tube, will ascend or descend within it. The amount of this ascent or depression is greater the smaller the tube. The amount also varies with the character of the liquid, while neither the character nor the thickness of the walls of the tube makes any difference.

Jurin's law of ascent and depression in capillary tubes: This is the most important law of capillarity, and holds true for liquids which wet the tube, while it is only slightly inaccurate for those which do not. It is that the height of ascent of one and the same liquid, in a capillary tube, is inversely as the diameter of the tube. It is from the exercise of this property that oil ascends in the wicks of lamps.

FIG. 24.

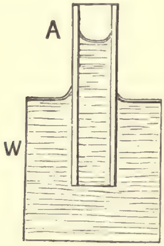
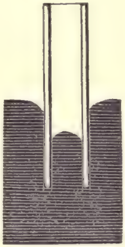


FIG. 25.



Osmosis—endosmose and exosmose: If two different liquids are separated by a thin porous partition, either organic or inorganic, a current sets in from each liquid to the other. As a result, one of the liquids increases in bulk, while the other diminishes, and both are more or less mixed. This phenomenon is called *diosmose*, and the currents are known as *endosmose* and *exosmose*, of which the former is the current toward the liquid which increases in bulk; the latter, the current from it. Endosmose usually takes place toward the denser liquid. The conditions necessary for the development of osmosis are, that the liquids be different, but capable of mixing; be of different densities; and that at least one of them can pass through the membrane.

The endosmometer: To one end of a long tube is bound a membranous bag filled with a strong solution, denser than water, and the bag is then immersed in a vessel of water. Gradually the level of the fluid in the tube rises, while the level of the water is lowered. In other words, endosmosis has taken place toward the denser liquid in the bag, while exosmosis also has occurred, as is proved by detecting some of the solution mixed with the water. This is not simply a process of filtering.

Diffusion of liquids: This refers to the gradual mixing of two liquids of different specific gravities when they are carefully placed, without mixing, in the same vessel, the liquid of lower specific gravity being uppermost. For example, by means of a funnel pour dilute sulphuric acid into a tall jar containing water colored by blue litmus. Be careful to have the end of the funnel resting on the bottom of the jar and pour the acid slowly so that it will form a layer on the bottom. Gradually the color will change to red, beginning at the bottom and progressing upward. By the end of 48 hours the change will be complete and the upper layers will be acid, a proof that diffusion has taken place throughout the entire mass. It has been found that different substances vary greatly in their rate of diffusion.

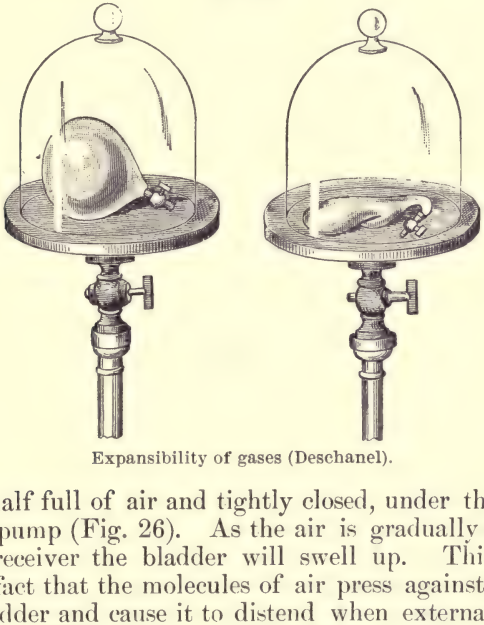
Dialysis: Depending on the fact that substances of the *gelatin* class, probably because of the large size of their molecules, have great difficulty in passing through minute apertures, we are able to separate many of these substances in solution by means of a *dialyzer*. This consists of a glass cylinder closed at one end by a piece of parchment. The mixed solution to be dialyzed is placed in the cylinder and it is partially immersed in a vessel containing a large quantity of water. In the course of a day or two the diffusible substances will be more or less completely removed from the mixed solution, having passed into the water. The gelatin type of substance, known as *colloids*, will still remain in the dialyzer. Colloids are substances, such as albumins, gums, resins, etc., which do not crystallize.

GASES.

Gases are bodies which have neither independent shape nor volume. Their molecules possess almost perfect mobility, darting about in all directions and continually tending to occupy greater space. Gases and liquids have some properties in common, while they differ only in degree in regard to others. Pressure and low temperature will convert all gases into liquids while heat will convert liquids into an aëriform state known as *vapor*, which obeys all the laws of gases. Gases as well as liquids possess the property of *fluidity* as opposed to *solidity*, but in a higher degree. Atmospheric air is taken as the type of gases in the experiments to be described. The two most important properties of gases are expansibility and compressibility.

Expansibility: This is the tendency which gases have of assuming a greater volume. It may be shown by placing a bladder, half full of air and tightly closed, under the receiver of an air-pump (Fig. 26). As the air is gradually exhausted from the receiver the bladder will swell up. This happens from the fact that the molecules of air press against the sides of the bladder and cause it to distend when external pressure is removed. When air is again admitted to the receiver the bladder reverts to its original form and size. Because of this property of *expansibility, tension,* or *elastic force,* gases are often called *elastic fluids.*

FIG. 26.



Expansibility of gases (Deschanel).

Compressibility: That gases are compressible can be shown by the *pneumatic syringe*. This consists of a stout glass tube closed at one end and provided with a tight-fitting piston. Pressure applied to the piston forces it down the tube and the air is compressed to a smaller volume. As soon as the force is removed the air regains its original volume, driving back the piston.

Weight of gases: That gases, as well as solids and liquids, have weight may be proved by weighing a hollow metal sphere both before and after the air has been exhausted from it by means of an air-pump. The difference in the two weights is the weight of the volume of air; 100 cubic inches of dry air at a temperature of 60° F. and under ordinary pressure weigh 31 grams. An equal volume of water weighs 773 times as much. The weight of gases in small quantities is inconsiderable; but large quantities, like the atmosphere, exert considerable pressure.

Pressures exerted by gases: The pressure exerted by gases is of two kinds:

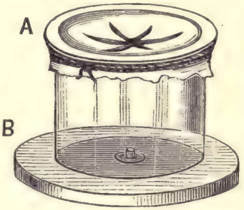
1. *That due to their expansive force*, which acts with equal strength on all points, both of the mass itself and of the vessel in which it is contained. This form of pressure may be demonstrated experimentally by an apparatus resembling that used to demonstrate equality of pressures in liquids.

2. *That due to their weight*, which follows the same laws as control pressure produced by the weight of liquids. Atmospheric pressure is an example of this kind.

Atmospheric pressure: The atmosphere in which we live is the layer of air which surrounds our globe. It is chiefly composed of oxygen and nitrogen in the ratio of 1 to 4, and its depth has been variously estimated at from 40 to 200 miles; but the most distant parts are extremely rarefied. It is held to the earth by force of gravity and rotates with it. Pressure due to its weight is exerted in all directions, acting at right angles to any surface, no matter what its position. The weight of a column of air 1 inch square, extending from the earth to the utmost limits of the atmosphere, is about 15 pounds at sea level; hence, the atmosphere exerts a pressure of 15 pounds on every square inch, or about 1 ton on every square foot. Any gas or liquid which exerts a pressure of 15 pounds to the square inch is said to exert a pressure of *one atmosphere*, and, as a result, this amount has become the unit of surface-pressure by gases. The pressure sustained by an average sized man is about 15 tons.

Crushing force of the atmosphere : This may be demonstrated by firmly fastening a piece of bladder across one end of a stout glass cylinder and pressing the other end, the edge of which is ground and well greased, on the plate of an air-pump (Fig. 27). As the air is exhausted from the cylinder, the bladder is depressed by the weight of the atmosphere above it, and finally bursts with a loud report, caused by the sudden entrance of air. This illustrates the downward pressure of the atmosphere.

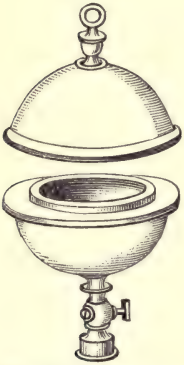
FIG. 27.



Burst bladder (Draper).

The Magdeburg hemispheres: These illustrate the fact that air-pressure acts in all directions. They consist of two hollow brass hemispheres (Fig. 28), whose edges fit tightly and are well greased. One of them has a stop-cock for attachment to the air-pump. As long as the hemispheres contain air they can be separated without difficulty, for the external atmospheric pressure is counterbalanced by the elastic force of the air in their interior. If the air is exhausted from their interior by an air-pump, a powerful effort will be required to separate them; and as this is the case in whatever position they are held, it follows that atmospheric pressure is transmitted in all directions. It is the elastic force of the contained air that, by exactly counterbalancing atmospheric pressure, prevents the crushing of any hollow vessel.

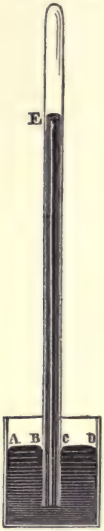
FIG. 28.



Magdeburg hemisphere (Draper).

Barometers are instruments for measuring atmospheric pressure. In their simplest form they depend on the experiment made by Torricelli, which gives the exact measure of the weight of the atmosphere. Take a glass tube about a yard long, seal it at one end, and completely fill it with mercury. Close the open end with the thumb, invert the tube, immerse the lower end in a small open vessel containing mercury, and then remove the thumb (Fig. 29). The tube being vertical, the column of mercury will finally come to a rest at a height which, at sea-level, is about 30 inches above the level of the mercury in the vessel. At the top of the tube, above the mercury, is an empty space, known as the *Torricellian vacuum*, which contains no air. As in studying hydrostatics, we have seen that the height of two columns of different liquids in communication with each other are inversely as their densities, it follows that atmospheric pressure is equal to that of a column of mercury 30 inches high. The denser the air the higher the column, and *vice versa.* On a mountain peak the height of the column of mercury is less, because atmospheric pressure is diminished. Depending on the principle of this experiment, three kinds of barometers are made :

FIG. 29.

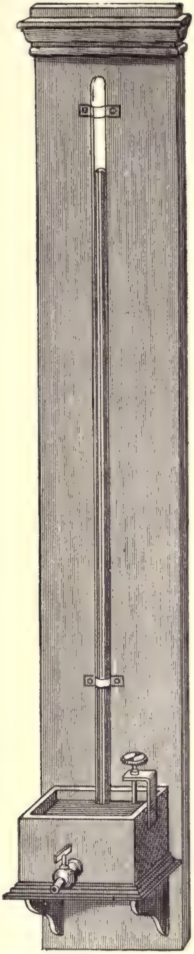


1. *Barometers using mercury*, such as the cistern, syphon, Fortin's, and Hooke's wheel barometers.
2. *Barometers using liquids other than mercury.*
3. *Barometers not using any liquid*, such as the aneroid.

Cistern barometer : This consists of a simple Torricellian tube, 33 inches long, filled with mercury, and dipping in an open cistern containing mercury (Fig. 30). The tube and cistern are fastened to a wooden support, which has at its upper part a scale for reading the height of the column. In this form of barometer there is an error in the readings, due to the fact that the level of the mercury in the cistern varies, depending on the amount contained in the tube, and consequently does not always coincide with the zero-mark of the scale.

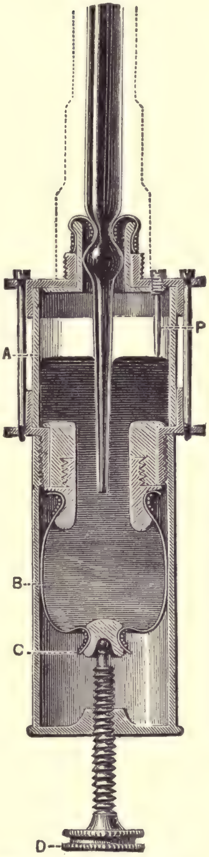
Fortin's barometer is simply a modification of the cistern barometer, designed to overcome this error (Fig. 31). It differs from the cistern barometer only in the fact that the base

Fig. 30.



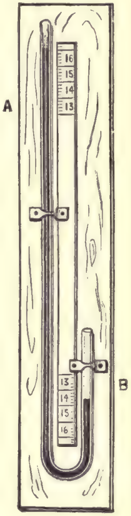
Barometer in its simplest form (Deschanel).

Fig. 31.



Cistern of Fortin's barometer (Draper).

Fig. 32.



Siphon barometer (Draper).

of the cistern is made of leather, and can be raised or lowered by means of a screw. In this way the level of the mercury in the cistern can be made to coincide with the zero-mark of the scale and a true reading obtained.

Gay Lussac's syphon barometer was also devised to overcome this *error of capacity.* It consists of a bent glass tube, one of the branches of which is much longer than the other and closed at the top; while the shorter branch is open above (Fig. 32). When the longer branch is filled with mercury, the shorter acts as a cistern, and the difference between the levels in the two branches is the barometric height. This apparatus is mounted on a wooden support provided with scales for reading the difference in level.

Hooke's wheel barometer is a syphon barometer especially intended to indicate good and bad weather. In the shorter branch of the tube there is a float, which rises and falls with the mercury. A string attached to this float passes around a pulley and has a small weight at its other end. The rise and fall of the mercury so turn the pulley that a needle attached to it will move around a scale to the corresponding points, such as *stormy*, *rain*, *change*, etc.

Barometers using liquids other than mercury: These are not of much value. They are very cumbersome because of the great size of the apparatus, and are inaccurate because the liquids wet the tube and also give off vapors freely. Glycerin and water are the liquids chiefly used. Jordan constructed one, using glycerin, in which the tube was about 30 feet long. Their value lies in the fact that smaller variations in atmospheric pressure can be detected by them, as their column is longer.

The aneroid barometer: This is the best example of those barometers which do not employ any liquid. It consists of a cylindrical metal box, the top of which is made of thin corrugated metal, so elastic that, after the air has been exhausted from the box, it readily yields to alterations in atmospheric pressure. The top is forced inward when pressure increases; but when pressure diminishes, its own elasticity, aided by a spring, causes it to move outward again. These motions are transmitted by delicate multiplying levers to an index which moves around a scale. These instruments are graduated by comparing them with an ordinary mercurial barometer; they are portable, and may be made very delicate; but are extremely liable to get out of order, and have to be regulated frequently. The scale gives readings, indicating the height of a column of mercury, under similar atmospheric conditions, and also the state of the weather, etc.

Barometric variations: The height of the column of mercury is affected by atmospheric pressure, capillarity, and temperature. As a consequence, it varies in the same place, not only from day to day, but also during the day. Two classes of variations are noticed:

1. *Accidental variations*, which present no regularity, but depend on the winds, seasons, or geographical position, and are common in our climate.

2. *Daily variations*, which are produced periodically, at certain hours of the day, with fair regularity, depending probably on atmospheric tides.

Uses of the barometer: The barometer is used: 1. *To ascertain heights* above sea-level. For accuracy, observations must be made on several successive days, and the average barometric height taken. 2. *Indirectly, to determine the state of the weather*, by remembering that usually in clear dry weather the atmospheric pressure is increased, and the column of mercury raised; while the opposite holds in rainy weather. At sea-level, the barometer is generally above 30 inches in fine weather, and below it in rainy, while a height of 30 inches indicates variable weather.

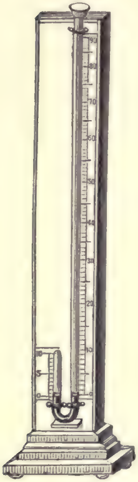
Elastic force of gases—Boyle's law: From observations on the action of gases when subjected to pressure, Boyle, in 1662, formulated the following law in regard to their compressibility and elastic force:

The volume of a given quantity of gas, the temperature remaining the same, is inversely as the pressure which it bears.

As a corollary of this it may be stated that, *The density of a gas is directly as the pressure.*

Boyle's law may be demonstrated by taking a U-shaped glass tube, with one arm short and closed above, while the other arm is long and open above. Pour mercury into the long arm till it is at the same level in both arms, as is shown in Fig. 33. The air in the short arm is now under ordinary atmospheric pressure only. Then pour mercury into the long arm till the volume of air in the shorter one is diminished one-half. It will be found that the difference between the levels of the mercury in the two arms is exactly equal to the barometric height at the time, representing a pressure of one atmosphere. By a similar procedure we could again reduce the volume of the air by one-half, by adding enough mercury to cause a pressure of two atmospheres. As the number of molecules in the air remains the same, though the volume be diminished one-half, the density is obviously doubled when the pressure is doubled.

FIG. 33.



Boyle's tube (Draper).

Manometers: These are instruments for measuring tension of gases, and resemble the apparatus used to demonstrate Boyle's law. The short arm of the U-shaped tube is connected with a closed receptacle containing the gas. Mercury is poured in the long arm till it rises to about the middle of the short arm. The difference in level is measured in inches and divided by thirty (the height of a column of mercury representing a pressure of one atmosphere). The result, plus one, gives the tension in atmospheres.

Mixture of gases: It has been found that all gases mix readily and rapidly if given the slightest opportunity. Experimentally, by placing different gases in communicating closed receptacles, and then analyzing them after different intervals, we have formulated the following law:

Gases mix with a rapidity which is inversely as the square root of their densities.

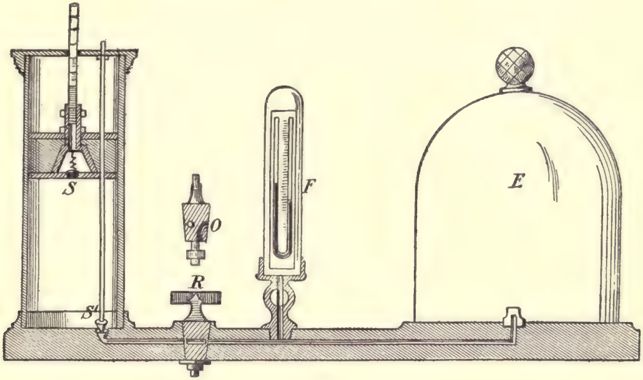
Absorption of gases by liquids: Many liquids will absorb gases, but the same liquid cannot absorb equal quantities of different gases. Bunsen has formulated the following laws:

1. The weight of gas absorbed is proportional to the pressure.
2. The quantity absorbed decreases with the temperature,

and is independent of the nature or quantity of other gases already held in solution by the same liquid.

Absorption of gases by solids: In most cases this is not a true absorption, but rather a coating of the surface of the solid by a layer of the gas. The greater the amount of surface, the more gas "absorbed." Consequently a porous substance like charcoal, with an immensely increased surface, can hold a large quantity of gas. This property is influenced slightly by the chemical nature of the gas and the solid. In metals there also appears to be a true solution or absorption of the gas, known as *occlusion*.

FIG. 34.

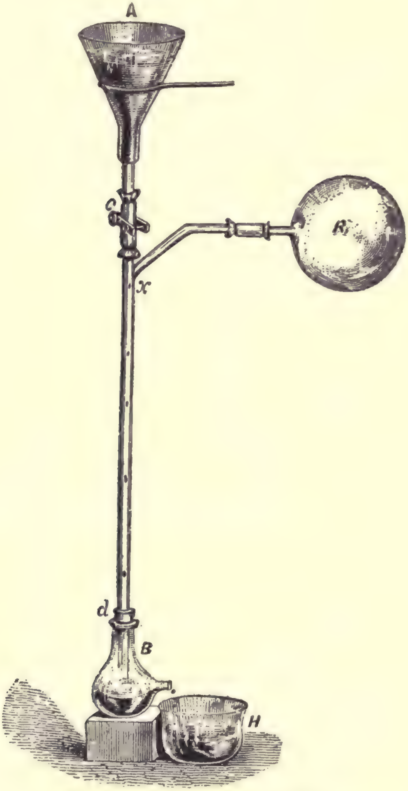


Air-pump (Deschanel).

Balloons are an illustration of the fact that the principle of Archimedes applies to bodies immersed in gases as well as in liquids. If they are lighter than the volume of the gas they displace, they will tend to rise or *float*. Depending on this, we construct balloons, which are hollow receptacles made of light, impermeable material, and filled with hot air or some gas of low specific gravity, preferably hydrogen. They will rise in the air till a point is reached where its density is so diminished that the weight of the volume displaced equals the weight of the balloon and its attached basket, etc.

Air-pumps: The air-pump is an instrument by which air in a given space can be greatly rarefied. In principle, it depends on the elastic force of air. If a portion of the air be removed from the receiver, the remainder will fill the entire space.

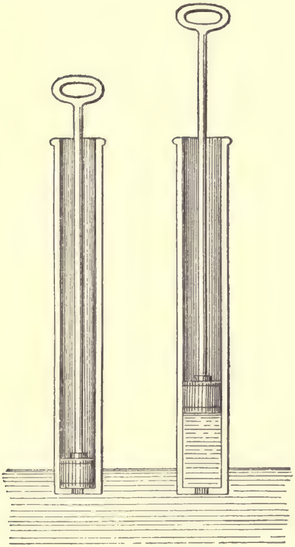
Fig. 35.



Sprengle's air-pump (Deschanel).

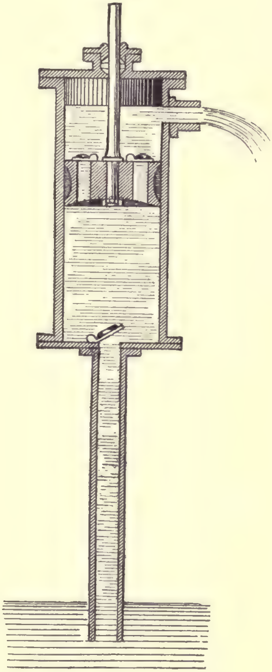
By successively removing portions, the air in the receiver becomes greatly rarefied. This is accomplished by having attached to the receiver a suction-pump. During the upward movement of the piston in the pump, air can flow into it from the receiver; but during the downward motion, the communication with the receiver is closed, the air in the pump being forced out through a valve. In this way successive portions of air are removed from the receiver. This is the simplest form of air-pump (Fig. 34); but more complex ones are made, which will produce greater rarefaction.

FIG. 36.



Principle of suction-pump (Deschanel).

FIG. 37.



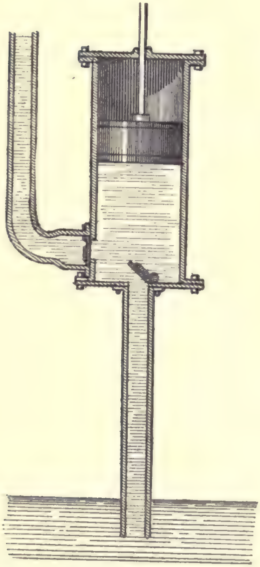
Suction-pump (Deschanel).

Sprengle's air-pump: This depends on the principle of converting the space to be exhausted into a Torricellian vacuum (Fig. 35). The receptacle to be exhausted is attached to an arm projecting from a long glass tube of small calibre. Mercury poured through this tube entangles and carries with it successive portions of the air in the receptacle, till finally it has taken almost all. This gives the most perfect vacuum known, air having been reduced to one millionth of its usual density. The bulbs of incandescent lights are exhausted in this way.

Pumps: These are machines which serve to raise fluids, either by suction or pressure, or a combination of the two. They depend on the principle that atmospheric pressure will force fluids to occupy the vacuum produced by the retreating piston. The essential features of any pump are *the barrel*, a cylinder of metal or wood in which works *the piston*, a metal or wooden cylinder; and *the valves*, which alternately close the apertures which connect the barrel with the pipes (Fig. 36).

Suction-pumps: The essential features are in the location and arrangement of the valves (Fig. 37). One is placed in the bottom of the barrel and the other in the piston; but both move upward in opening. When the piston rises a vacuum is produced in the barrel; the valve in the piston is kept closed by atmospheric pressure, which forces water through the tube into the barrel, opening the lower valve in the process. When the piston descends, the valve in the barrel closes by its own weight; consequently the water in the barrel is forced through the piston, opening its valve. When the piston again rises the process is repeated, and the water which passed through the piston is carried upward with it as its valve is closed.

FIG. 38.



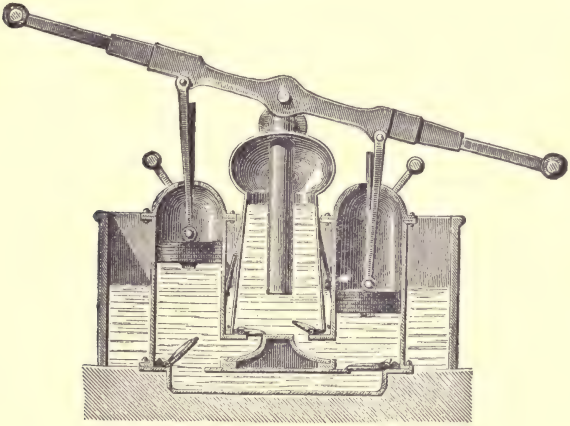
Suction-pump (Deschanel).

Though these are called *suction-pumps,* it can be seen that there is no process of suction concerned. Atmospheric pressure does the whole work of forcing water into the barrel, and consequently this form of pump will only be available when the barrel is at a less height from the surface of the water than the barometric height of a column of water. In practice this limit is about 26 feet at sea-level.

Force-pump: The ordinary force-pump is really a combination of the effects of suction and pressure. It differs from the suction-pump in having no valve in the piston and in having a pipe leading from the bottom of the barrel. To this pipe is attached a valve which opens outward, while the valve in the bottom of the barrel opens upward, as in the suction-pump (Fig. 38). When the piston is raised water enters the barrel by the lower valve, being forced up by atmospheric pressure; but the valve in the side pipe remains closed, as it is pressed inward by atmospheric pressure. During downward motion of the piston, the water is forced out of the side pipe, opening its valve; while the valve at the bottom of the barrel closes. The height to which water can be raised by this pump depends solely on the motive power, though the barrel itself must be near the water-supply.

Fire engine: The ordinary fire engine (Fig. 39) consists of two force-pumps, which play into a common reservoir containing in the upper portion—known as the *air-chamber*—air

FIG. 39.



Fire engine.

compressed by the working of the engine. This serves to give a steady stream, by keeping a fairly constant pressure on the escaping water.

SOUND.

The science of acoustics: This science comprises the study of sounds, and of the vibrations of elastic bodies.

Sound: The sensation excited in the organ of hearing by these vibratory motions, when transmitted to it through an elastic medium, usually the air, is called *sound*. It is the result of rapid oscillations of the molecules of elastic bodies, and is propagated by all gases, solids, and liquids, but cannot be propagated in vacuo. A body which produces a sound is called a *sonorous body*. A *noise* is either a sound of very brief duration, like the report of a cannon; or else a confused mixture of discordant sounds, like the noise of waves. *Musical sound* is that which produces a continuous sensation, and whose musical value can be estimated.

Sound-waves: The vibrations of the molecules of elastic media, through which sound is propagated, take the form of *waves* or *undulations*, whose length is the space through which the sound can travel during one complete vibration of the sonorous body. These waves, when not enclosed, as would be the air in a speaking-tube, extend outward in all directions, forming *spherical waves*.

Intensity of sound: From experiments it has been found that the force or intensity of sound, as heard through the air, depends on various conditions as follows:

1. It is inversely as the square of the distance of the sonorous body from the ear;
2. It increases with the amplitude of the vibrations—that is, with the height of the sound-waves;
3. It varies as the density of the air in which it is produced;
4. It is modified by motion of the atmosphere and direction of the wind;
5. It is strengthened by a neighboring sonorous body, such as a sounding-board.

Velocity of sound: The velocity of sound in air at 60° F., is about one-fifth of a mile per second. In water its velocity is about four-fifths of a mile per second, while in glass it will travel at a rate of over three miles per second.

Reflection of sound: When sound-waves meet with an obstacle, they are reflected upon themselves, following the same laws as govern the reflection of light and radiant heat:

The angle of reflection is equal to the angle of incidence; and both the reflected and the incident wave-rays are in the same plane, perpendicular to the reflecting surface.

An *echo* is the repetition of a sound in the air, caused by its reflection from some obstacle.

Perception of sound: The limit of perceptible sounds is found in the case of deep sounds to lie between sixteen and twenty-four single vibrations per second of the sonorous body; while in that of high sounds it is about 40,000 per second. Many people, however, are deaf to notes above 16,000 or even 12,000 vibrations per second.

Influence of tubes on sound: It is found that sound transmitted in tubes loses its intensity very slowly, especially if the tubes are straight and cylindrical. *Speaking-tubes* are examples of this fact. The *megaphone* transmits sounds to a great distance, not only because it produces parallelism in the sound-waves, but also because it allows a large mass of air to be set in consonant vibration before it begins to be diffused.

Properties of musical notes: A simple musical note results from continuous rapid isochronous vibrations. Musical notes are in most cases compound. The tune yielded by a tuning-fork is *simple;* that by a flute or wide-stopped organ-pipe nearly simple; while that yielded by a musical string is *compound*.

Musical notes have three leading qualities:

Pitch, which depends on the number of vibrations per second of the sonorous body;

Intensity, which depends on the extent or amplitude of the vibrations;

Timbre or *quality*, which depends on the character of the body producing the note.

Musical intervals: The interval between two notes is the ratio obtained by dividing the number of vibrations of one by the other. For example, the note C is produced by m vibrations per second and the note X by n, n being greater than m. The interval from C to X is the ratio $n : m$. Although two notes may be separately musical, the result when they are sounded together is unpleasant unless they are concordant. If two notes are separated by an interval in the ratio 2 : 1, their interval is called an *octave.* If three notes are separated by intervals in the ratio 4 : 5 : 6, they form a *harmonic triad;* and if they are sounded with a fourth note, which is the octave of the first one, they constitute a *major chord.* If the ratio between the three notes is 10 : 12 : 15, they are slightly dissonant, but not unpleasantly so. If these are sounded with the octave to the first one, they form a *minor chord.*

The musical scale: The series of sounds connecting a musical note C with its octave c is called a *diatonic scale* or *gamut.* The notes composing it are indicated by the letters *C, D, E, F, G, A, B.* The scale is continued by taking the octaves of these notes—*i. e., c, d, e, f, g, a, b;* and again the octaves of these, and so on. If the vibrations of C be denoted by m, the vibrations of the other notes will be as given in the following table:

do	re	mi	fa	sol	la	si	do
C	*D*	*E*	*F*	*G*	*A*	*B*	*c*
1. m	$\frac{9}{8}$m	$\frac{5}{4}$m	$\frac{4}{3}$m	$\frac{3}{2}$m	$\frac{5}{3}$m	$\frac{15}{8}$m	2. m

It will be noticed that the *intervals* between any two notes, obtained by dividing the larger fraction by the smaller, are one of the fractions $\frac{9}{8}$, $\frac{10}{9}$, or $\frac{16}{15}$. The first two of these are called *tones*, and the latter a *semitone.* The number of vibrations for C is in dispute, the standard in England being 264. As long as the rest of the notes are concordant with it, it may vary a little without harm.

HEAT.

Nature of heat: The term *heat* is used to express both a particular sensation and also to describe the particular state or condition of matter which produces this sensation. Besides producing this sensation, it acts in various ways upon all bodies: it boils water, melts ice, makes metals red-hot, etc. Two theories as to its cause have been propounded:

The theory of emission: This holds that heat is caused by a subtle, imponderable fluid which surrounds the molecules of bodies and can pass from one to another. These *heat atmospheres* exert a repelling influence on each other, in consequence of which heat opposes the force of cohesion.

The theory of undulation: This assumes that there is an imponderable elastic ether pervading all matter and space. The heat of a body, caused by very rapid vibrations of its molecules, sets up in this ether rapid vibratory movements, which, when communicated to other bodies, causes them also to vibrate more rapidly; that is, to increase in temperature. The hottest bodies are those in which these movements have the greatest amplitude and velocity. Heat, therefore, is not substance, but a *condition of matter*, which can be transferred from one body to another. This theory is the one generally accepted, as it can better explain the conditions produced in a body by heat.

General effects of heat: The general effects of heat on a body may be classed under three heads:

1. Part is expended in *raising the temperature* of a body by increasing the activity of its molecules;

2. Part is expended in overcoming the attraction of the molecules for each other and augmenting the amplitude of their oscillations, by which a *change in volume* or *state* is produced;

These two effects are classed as *internal work.*

3. Part is expended in *overcoming atmospheric pressure* during the change in volume, classed as *external work.*

Definition of temperature: Temperature is the ability to give or receive heat. The body which gives heat to another has a higher temperature and is said to be *warmer;* while the one that receives heat from another has a lower temperature. The temperature of a body has no exact relation to the amount of heat it possesses.

Measurement of temperature: As heat causes all bodies to expand, its temperature may be measured by instruments which depend on this expansion, known as *thermometers*. Liquids are generally used in the construction of these instruments, as their rate of expansion is more convenient than that of solids or gases; mercury and alcohol being practically the only liquids used. The great advantage of mercury is that it only boils at a very high temperature, has a regular rate of expansion, and gives very accurate indications. Alcohol is used where temperatures below the freezing-point of mercury (—40° F.) are to be recorded, as its freezing-point is very low.

Mercurial thermometers: These consist of a capillary glass tube, at the end of which is blown a *bulb*. The bulb and tube are filled with mercury and then heated to the boiling-point, to expel all air. The open end of the tube is then sealed. The confined liquid indicates temperature by expansion or contraction. The scale of the thermometer is established by placing the bulb in some freezing-mixture to get the zero-point, and then in boiling water for the highest point. The intervening space is then divided according to the various systems.

Fahrenheit scale: This system, the one most used in this country, takes as it highest point the boiling-point of water; while its zero-point is the temperature obtained by mixing equal weights of sal ammoniac and snow. The intervening space on the scale is divided into 212 equal divisions or *degrees*. At the temperature of melting ice, the zero-point of other scales, this registers 32°.

The centigrade scale: In this the boiling-point of water is taken as the highest point, and the melting-point of ice as the lowest, or zero. The intervening space is divided into 100 degrees.

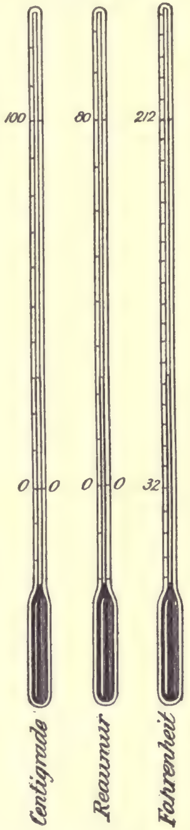
The Reaumur scale: In this the zero and highest point are the same as in the centigrade scale; but the intervening space is divided into 80 degrees only.

Conversion from one scale to another: On the Fahrenheit scale there are 180° (212°—32°) between the freezing- and the boiling-points of water; while on the centigrade scale there are 100°. These ranges being equal, 180° F. = 100° C., or 1° F. = $\frac{5}{9}$° C. Remembering these values, and also the fact that zero Fahrenheit is 32° below freezing-point, we can readily convert from one scale to another. The given

Fahrenheit temperature minus 32° multiplied by $\frac{5}{9}$ will give the centigrade temperature; while any centigrade temperature multiplied by $\frac{9}{5}$ and increased by 32° will give the Fahrenheit temperature (Fig. 40).

Example—Convert 77° F. to centigrade: $77-32=45$. $45\times\frac{5}{9}=25°$ C.

FIG. 40.



Thermometric scales (Deschanel).

Alcohol thermometers: These are similar in construction to mercurial thermometers, except that they are filled with colored alcohol. As the expansion of alcohol is irregular near its boiling-point, they are graduated by comparison with mercurial thermometers. They are used to record temperatures below −40° F.

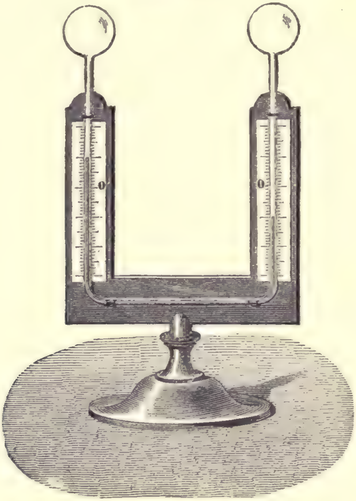
Varieties of thermometers: There are many varieties of thermometers constructed for special purposes. Among them are the differential, recording, and clinical thermometers.

Differential thermometer: This is really a thermoscope for indicating difference in temperature between its two bulbs, but not for measuring the amount. It consists of a bent glass tube (Fig. 41), having at either end a bulb, and is partly filled with colored liquid. The bulbs are placed in different liquids or places, and the one which becomes warmer causes its contained air to expand and force the liquid in the direction of the other.

Recording thermometers: These are thermometers which have, inside their tube, an index which moves with their liquid (Fig. 42). According to the character of the index and the liquid, they are made to record the highest or lowest temperature reached.

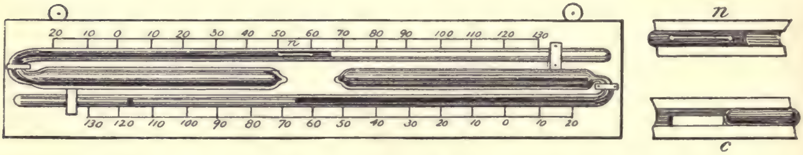
They are sometimes called maximum and minimum thermometers, and are used for meteorological observations at night.

Fig. 41.



Clinical thermometer: This is a maximum recording thermometer, which gives great delicacy of indications over a short range of temperature, usually 94° F. to 112° F. Delicacy is attained by having a very small capillary tube and a large bulb of thin glass. By making a constriction in the tube near the bulb, the column of mercury is always broken when it begins

Fig. 42.


20 10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
n
130 120 110 100 90 80 70 60 50 40 30 20 10 0 10 20
n
c

Rutherford's maximum and minimum thermometers (Deschanel).

to contract, consequently it remains at the same level in the tube, and thus records the maximum temperature. The constriction interferes with the passage of the mercury sufficiently to gain this effect, but cannot stop its expansion.

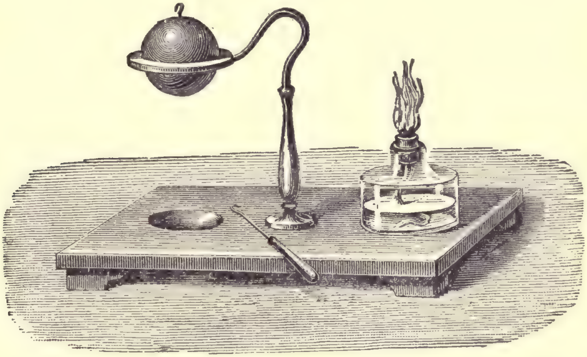
Pyrometers: These are instruments for measuring temperatures above the boiling-point of mercury. They depend on the electrical properties of bodies when affected by heat; or on the expansion of gases and vapors.

Delicacy and accuracy: A thermometer is *delicate* when it is quickly affected by changes of temperature, and indicates very slight differences in temperature. It is *accurate* when it gives correct readings. Neither one implies the other. A thermometer may be either delicate or accurate, or both, or neither.

CHANGE OF VOLUME.

Expansion due to heat: All bodies expand by the action of heat. As a rule, gases are the most expansible, then liquids, and lastly solids. Solids may expand in one dimension, *linear expansion;* in two dimensions, *superficial expansion;* or in three dimensions, *cubical expansion*, or expansion of volume. That *solids* do expand may be shown by a Gravesande's ring

FIG. 43.



Gravesande's ring (Deschanel).

(Fig. 43). This consists of a brass ball which, when cool, passes freely through a ring almost of the same diameter. When the ball has been heated, it will no longer pass through till it has again cooled.

The expansion of *liquids* is shown by the ordinary thermometer; and that of *gases* by the differential thermometer. With gases and liquids only cubical expansion is considered.

Expansion of solids: The *coefficient* of *linear* expansion is the elongation of the unit of length of a body when its temperature rises from 0° C. to 1° C. That of *superficial* expansion is double this, and that of *cubical* treble it. The coefficient is expressed as a fraction of the size of the body at 0° C. The coefficients vary, not only with different bodies, but also with their physical condition. They increase with temperature, and are not quite regular. Metals expand with almost irresistible force, consequently allowance must be made for this in all metal-work. Water-pipes are fitted with telescopic joints. A small space must be left between the ends of rails on railroads. Advantage is taken in many ways of this expansion by heat and subsequent contraction on cooling. Tires are heated before being put on wheels, so that that they may be tight when cool, etc.

Expansion of liquids: In the case of liquids, there is both an *apparent* expansion and an *absolute* or *real* expansion. If a glass flask with narrow stem be heated, the level of the liquid in the stem will rise. This is the apparent expansion which we can see. But as the glass of the flask also expanded, it caused an error, concealing part of the expansion of the liquid. The real or absolute expansion is that which would be noticed if the flask did not expand. The coefficients are numerically greater among liquids than among solids. Though irregular, their deviation is less; while no two liquids have the same coefficient. As the coefficient is the increase of the unit of volume when heated through a single degree, we have coefficients of both apparent and real expansion. The force exerted by liquids while expanding is very great, being equal to that which would be expended in bringing the liquid back to its original volume if exerted in the form of pressure. There are some exceptions to the rule, that heat causes expansion. *Water*, when heated from 32° to 39.2° F., decreases in volume; but again expands if its temperature rises higher. It is said, therefore, to be at its maximum density at 39.2° F. (4° C.).

Expansion of gases: Gases expand more regularly and to a greater degree than all other substances. The coefficients of expansion of the various gases differ so slightly that they may be considered as practically the same. We can say, therefore, that the volume of any gas at 32° F. is augmented by $\frac{1}{491}$ for every degree Fahrenheit it is raised above that point. As the density of gases is decreased when they expand, we can readily understand why the hot, bad air in a room rises to the top. Taking advantage of this, we can ventilate a room by letting out the hot air at the top, and letting in the pure, colder air at the bottom.

CHANGE OF STATE.

Fusion: The continued application of heat to a solid body increases the activity of its molecules, till finally molecular attraction is overcome, and the body is said to *fuse* or *melt;* passing from the solid to the liquid state. Some substances, however, such as paper, wood, wool, etc., do not fuse, but are decomposed. Some few substances have been considered *refractory* or incapable of fusion; but this is probably because we cannot produce a high enough temperature. Pressure has only a very slight effect on the fusion-point. Some substances pass from the solid to the liquid state without showing any definite melting-point, but gradually soften till they become liquid. This condition is known as *vitreous fusion.*

Laws of fusion: By experiment it has been found that fusion is governed by the following laws:

1. *Every solid has a definite and fixed fusing-point;*
2. *During fusion the temperature remains the same, no matter what the intensity of the source of heat.*

Alloys: Mixtures of two or more metals, known as *alloys,* generally fuse at a lower point than would any of the metals of which they are composed when melted separately. *Wood's fusible metal,* composed of cadmium, 2 parts; tin, 2 parts; lead, 4 parts; and bismuth, 8 parts, melts at about 70° C.;

while the melting-points of the various component metals range from 228° to 335° C. An alloy of mercury with some other metal is called an *amalgam.*

Fluxes: Depending on this lower melting-point of alloys, certain substances, known as *fluxes,* are added to ores to help in their reduction to a metallic state, less heat being required in the process.

Latent heat of fusion: This is the heat absorbed by a body during its passage from the solid to the liquid state. It is expended in the mechanical work of causing the change of condition, and its only effect is to maintain the liquid state. It is not indicated by the thermometer.

Example: If a pound of water at 80° C. be mixed with a pound of water at zero, the temperature of the mixture is 40° C. But if a pound of crushed ice at zero be mixed with a pound of water at 80°, the ice melts and we get two pounds of water at zero. Consequently it requires as much heat to melt one pound of ice as it does to raise one pound of water through 80°. This 80° of heat is the *latent heat* of fusion of one pound of ice, or the latent heat of water. Every liquid has its own latent heat.

Solution: A body is said to *dissolve* when it becomes liquid because of the attraction between its molecules and those of a liquid. When a liquid dissolves as much of a solid as it can at a certain temperature, it is said to be *saturated;* but the weight dissolved usually increases with the temperature. In this process, as in fusion, a certain amount of heat becomes latent, tending to reduce the temperature of the solution. Sometimes chemical combination, occurring at the same time, produces enough heat to neutralize this tendency and raise the temperature of the solution.

Solidification: The passage of a body from the liquid to the solid state is known as *solidification* or *congelation.* The laws controlling this process are:

1. *Every body solidifies at a fixed temperature, which is the same as its melting-point.*

2. *The temperature remains constant during the entire process of solidification.*

Alcohol only recently has been frozen.

Crystallization: Bodies which pass slowly from the liquid to the solid state usually assume regular geometrical forms, such as the cubical, prismatic, etc. This is due to their property of polarity.

Retardation of solidification: The freezing-point of pure water can be diminished several degrees if the water be kept perfectly still while being cooled. At the slightest agitation, however, it instantly solidifies and the temperature rises to 0° C. Though it may be cooled below zero without freezing, by no device can ice be warmed above 0° C. without melting. Melting of ice is, therefore, taken as the lower fixed point on the thermometric scale. A very rapid agitation also prevents the formation of ice. Great pressure not only retards the freezing-point of water, but prevents its complete solidification by opposing the tendency to expansion on freezing.

Change of volume during solidification and liquefaction: Most bodies expand more rapidly as they approach their melting-point; and this is followed by a further expansion during liquefaction; while, conversely, they contract when they again become solids. Water is a remarkable exception to this rule, as it expands by about 10 per cent. at the moment of solidification, and contracts to the same degree on melting. The expansive force accompanying this process is terrific. It splits stones, bursts water-pipes, etc. Cast-iron, sulphur, and type metal all expand slightly at the point of solidification, and can, therefore, be used for making casts. Gold, silver, and copper contract and make imperfect casts; hence coins of these metals must be stamped with a die.

Freezing-mixtures: The absorption of heat in the passage of bodies from the solid to the liquid state has been used to produce artificial cold. This is effected by mixing together substances which have an affinity for each other, one of which at least is a solid. Chemical affinity accelerates the fusion, and the portion which melts robs the rest of the mixture of a large portion of sensible heat, which becomes latent. If the mixture cannot supply sufficient sensible heat, the latter will be absorbed from all surrounding substances. When ice is mixed with salt in the proportion of two parts of the former to one of the latter, the ice is rapidly melted, the rapid thaw involving a rapid disappearance of heat. If the mixture surrounds a liquid at the ordinary temperature, and if care is taken to prevent the ice from obtaining the necessary heat from other sources, the heat will be abstracted from the liquid, and in a short time its temperature will be so reduced that it will become frozen. The temperature obtained by the mixture of ice and salt, or snow and salt, is about 0° F. Other freezing-mixtures are snow and crystallized chloride of calcium (3 to 4), nitrate of ammonium and water (equal parts), sulphate of soda and hydrochloric acid (8 to 5).

Vapors: These are the aëriform fluids into which volatile substances, such as water, mercury, etc., are changed by the application of heat. *Volatile* liquids are those which will form vapors directly; while *fixed* liquids are those, such as fatty oils, which do not form vapors without undergoing chemical decomposition. Many solids, such as camphor, arsenic, ice, etc., can directly form vapors without first becoming liquid. Vapors are transparent, like gases, and generally colorless.

Vaporization: This is the general term applied to the passage of a liquid to the gaseous state. *Evaporation* especially refers to the slow production of vapor at the free surface of the liquid; and *boiling* to its rapid production in the mass of the liquid itself. Evaporation can take place through a wide range of temperature, though it seems to cease below a certain point; for instance, − 10° C. in the case of mercury; while boiling, under ordinary pressure, only takes place at a fixed temperature.

Elastic force of vapors: Like gases, vapors have a certain elastic force, and thus exert pressure. This force, known as *tension*, varies with different vapors. This, and also the fact that in a vacuum all volatile liquids are instantly volatilized, may be proved by the following experiment: Take four barometer tubes, filled with mercury and inverted in a trough of mercury, as for barometers. The Torricellian vacuum will appear at their tops. Let one tube serve as a barometer, but add a few drops of water, alcohol, and ether to the other tubes respectively. When the liquids reach the vacuum the column of mercury falls instantaneously. As this cannot be due to the small weight of the liquids introduced, it must be caused by the elastic force of the vapors formed. As the depression in the three tubes varies, though the same amount of fluid was added to each, we can see that at the same temperature vapors of different fluids have different elastic forces.

Saturated vapor: If, in the above experiment, more ether be added to the tube containing its vapor, the depression of the mercury will become greater; but after the addition of successive quantities, a point will be reached when the additional ether will cease to vaporize, and will remain as a liquid on top of the mercury. The vapor above the mercury is now said to be *saturated*, as it is in contact with its liquid and as much has vaporized as possible. By raising or lowering the tube, the column of mercury will remain at the same height, and we will thus increase or diminish the pressure on this vapor. We will then see that compression causes a portion of such a vapor to return to the liquid state; while under a diminution of pressure a portion of the excess of liquid vaporizes. This shows that *saturated vapors* do not obey Boyle's law, but that their tension and density remain the same in all cases.

Unsaturated vapors: Like gases, unsaturated vapors obey Boyle's law. If, in the above experiment, only a small quantity of ether be introduced so that its vapor is unsaturated, it will be found that when the tube is slightly raised the column of mercury will rise also; and *vice versa*. This shows that the volume of the vapor has diminished or increased *inversely* as the pressure. When an unsaturated vapor is heated its volume increases like that of gas.

Evaporation: This process takes place continuously at the surface of seas, lakes, etc. The vapors rise, condense to form clouds, and finally fall as rain. It is this process which dries wet clothing when exposed to the air. It has been found that four causes influence its rapidity:

1. Increase of temperature hastens it by increasing the elastic force of the vapors;
2. It varies inversely as the degree to which the surrounding atmosphere is saturated with the same vapor;
3. Consequently it is hastened by the removal of this surrounding atmosphere by winds, etc.;
4. It depends directly on the amount of surface exposed.

Ebullition or boiling: This, the rapid production of elastic bubbles of vapor in the mass of the liquid itself, has been proved subject to the following laws:

1. *The temperature of the boiling-point increases with the pressure;*

2. *Under the same pressure the boiling-point of any liquid is always the same, but each liquid has its own boiling-point;*

3. *Whatever the intensity of the source of heat, the temperature remains constant during the process of boiling.*

Influences affecting the boiling-point: The boiling-point of a liquid is raised when less volatile substances are dissolved in it. Water which boils at 100° C. will boil at 109° C. when saturated with common salt, at 135° C. when saturated with potassium carbonate, and at 179° C. when saturated with calcium chloride.

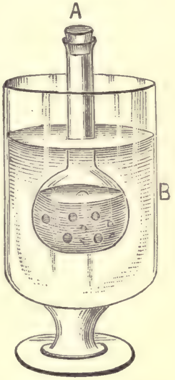
The character of the vessel in which fluid is boiled affects the boiling-point. If water is boiled in a rough-iron pot, violent ebullition is produced at 211° F., a degree below the true boiling-point. If the surface is smooth, the temperature may rise to 214° F. before it is fairly established. This is the result of adhesion between the molecules of the vessel and those of the fluid.

Many liquids, as sulphuric acid, boil in a very irregular manner, the temperature rising a number of degrees above the true boiling-point. There is then a sudden violent rush of vapor, and the temperature falls to the standard, to rise again in the same manner. These irregular actions cease when some object which affords points for the escape of vapor is thrown into the vessel. In the preceding case, introduce a few pieces of platinum into the liquid and it will boil quietly.

Effect of pressure on the boiling-point: Pressure is the all-important factor in determining the boiling-point of a liquid, as a liquid can only boil when the tension of its vapor equals the pressure it supports. The ocean of air surrounding the earth and resting upon it by the influence of gravitation is rare above, but denser as we descend. It follows that water boiled at a high elevation has but little air above to resist or hold vapor tending to escape. Therefore the water boils at a low temperature. At the earth's surface a longer column of air, consequently more weight, is sustained, and more heat-energy is necessary to force away vapor rapidly. The boiling-point varies with the air-pressure. Therefore we can alter the boiling-point by altering the pressure.

Culinary paradox: Dependent upon this fact is a curious phenomenon, known as the culinary paradox, in which water is boiled by the application of cold (Fig. 44). A flask, *A*, is half filled with boiling water, quickly corked, and placed, bulb and neck, in cold water, *B*. The liquid in the bulb at once begins to boil, and continues in that condition for some time. If, before it ceases, the cork is removed, there is a sudden inrush of air, showing that the interior was in a condition of partial vacuum.

FIG. 44.



Culinary paradox.

The explanation is simple: when the flask was placed in cold water the steam filling its upper part was condensed, and a vacuum was formed, in which the fluid boiled by virtue of the law just demonstrated, that reduction of pressure is attended by lowering of the boiling-point.

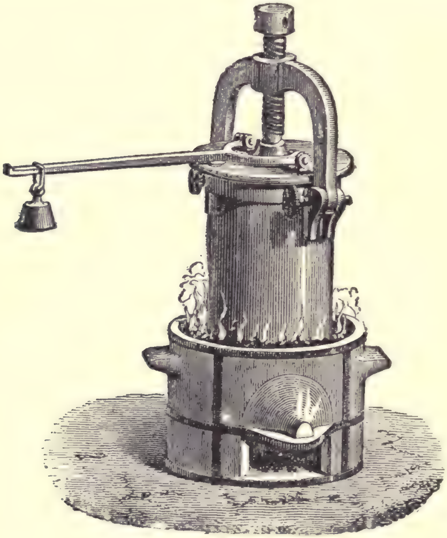
The **vacuum pan**: This lowering of the boiling-point by diminution of pressure is made use of in various ways in the arts. Danger of burning attends the production of sugar. To obviate this difficulty the syrup is boiled in a closed vessel, known as a *vacuum pan*, from which air can be exhausted and boiling induced at a low degree.

Papin's digester: Conversely, the raising of the boiling-point by increasing the temperature is made use of in Papin's digester (Fig. 45). This is a closed boiler in which water is heated under pressure and its boiling-point raised. With this rise it gains increased power of solution over all kinds of animal and other substances. Tendons, cartilage, and other gelatinous bodies placed therein under a pressure of four or five atmospheres are quickly dissolved. In this manner albuminoid substances are extracted from bones.

The heights of mountains may be measured by the temperature of the boiling-point. There is a diminution of 1° F. in the boiling-point of water for every rise of 600 feet above sea-level.

Latent heat of evaporation: As the temperature during boiling remains constant, it follows that a considerable quantity of heat becomes latent during evaporation, which is again given off when a saturated vapor passes to the liquid state. This quantity of heat is known as the *latent heat of evaporation*, and is expended in overcoming molecular cohesion and replacing it by repulsion. As in the case of fusion, this latent heat varies in different substances. It takes as much heat to convert one pound of water at the boiling-point into steam at the same temperature as it would to raise five hundred and thirty-six pounds of water through one degree. When condensed, the steam will give off exactly this same amount of heat.

FIG. 45.

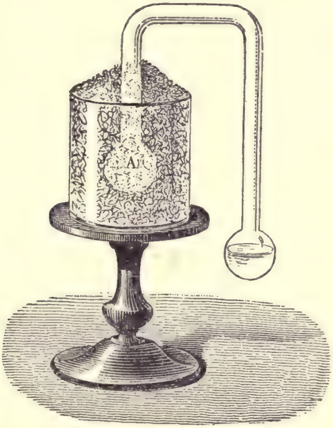


Papin's digester (Deschanel).

Cold produced by evaporation: Advantage is taken of this absorption of latent heat during evaporation in the process of making artificial ice, etc. A liquid when evaporating must get this latent heat from some source; from its own bulk if it cannot be obtained from other sources. As a consequence, the temperature of the liquid sinks. Some highly vaporizable liquid, as ether or ammonia, is caused to volatilize by diminution of pressure, accomplished by a pump. An intensely cold fluid is produced, which is used by some suitable device to abstract heat from the water to be frozen.

Wollaston's cryophorus furnishes an experimental proof of this fact. A small quantity of water is introduced into a bent glass tube, which has a bulb at either end (Fig. 46). The water in the tube is boiled to expel all air, and the tube is then hermetically sealed. Turn the tube, which now contains only water and vapor of water, so that all the water is in one bulb, and place the other in some freezing-mixture. The vapor in the tube *A* is then condensed by cold, and the water in the other bulb rapidly yields more to replace it. The latent

FIG. 46.



Cryophorus (Deschanel).

heat absorbed in this process of vaporization of the water so cools it that it quickly freezes. The cooling effect of vaporization is applied in surgery for the production of local anæsthesia. A fine spray of ether is directed upon the surface by means of an atomizer. By its rapid evaporation heat is abstracted from the part and intense cold produced, attended by loss of sensibility, and the knife can be used without causing pain. A similar arrangement is utilized for freezing soft tissues in making microscopic sections.

Liquefaction of vapors: The passage of a vapor from the aëriform to the liquid state is known as its *liquefaction* or *condensation.* This process may be due to cooling, to compression, or to chemical affinity. During this process the latent heat of evaporation becomes free—that is, it affects the thermometer. It equals in amount that absorbed during vaporization.

Distillation: The process by which liquids of different volatilities may be separated, or by which a volatile liquid may be separated from substances which it holds in solution, is known as *distillation.* This process is based on the fact that the liquid whose boiling-point is lowest evaporates more rapidly than those with which it is associated. The mixture is heated in a vessel called the *still.* It should not boil, but only simmer gently. The formation of spray and carrying over of minute portions are thus avoided, and a purer distillate obtained. As vapor arises in the still it is received in the *worm.* In this the steam is condensed and escapes below in a fluid state.

As a rule, the first fifth and the last two fifths of a specimen are not collected. The first contains vapors which are objectionable; the last two, salts in increasing quantity; and the liability to the formation of spray and destruction of the whole distillate is very great.

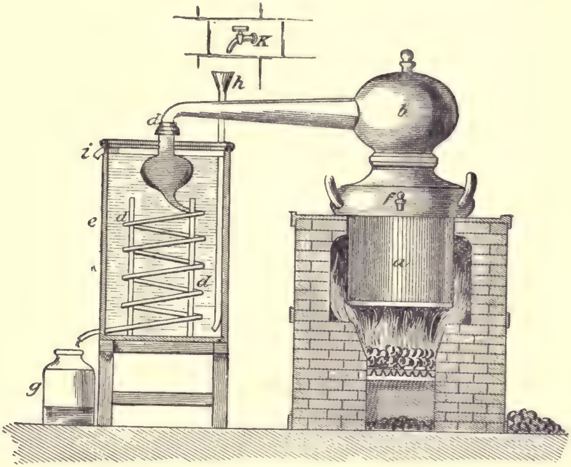
It is an excellent practice to follow a species of fractional distillation, collecting the distillate by tenths and mingling those which are pure.

The still: The essential features of a still (Fig. 47) are a vessel, *a*, containing the liquid; a head, *b*, which fits tightly on *a*, and from which a tube leads to the worm, *d*, which consists of a long spiral tube placed in a vessel kept constantly full of cold water.

Sublimation: A similar process to that of distillation, but whose product is a solid, is known as *sublimation*. Certain solids, such as camphor, iodine, etc., pass directly, on the application of heat, from the solid to the gaseous state, and again, by the application of cold, revert to the solid state. To separate such substances from impurities or mixtures, this process of *sublimation* is employed.

Liquefaction of gases: We have already seen that any saturated vapor may be liquefied by increasing pressure or lowering the temperature. As unsaturated vapors behave like gases, obeying Boyle's law, we can fairly suppose that all gases are simply unsaturated vapors far removed from their point of saturation. As unsaturated vapors may be reduced to a state of saturation and then liquefied, it follows that similar methods will liquefy gases.

Fig. 47.



Still (Deschanel).

Faraday's experiment: The first to liquefy any of the so-called *permanent* gases was Faraday. He enclosed in one end of a bent glass tube substances whose chemical action would produce the gas to be liquefied, and sealed the tube. In proportion as the gas is formed in the tube its pressure increases, till it finally liquefies and collects in the other arm of the tube, more especially if this arm be placed in a freezing mixture. Many gases are now sold in the liquid state as articles of commerce. Hydrogen has been liquefied.

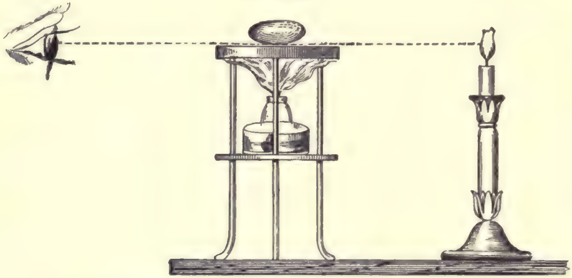
Mixtures of gases and vapors: It has been found that every mixture of a gas and a vapor obeys *Dalton's laws*, as follows:

1. *The pressure and the quantity of vapor which saturates a given space are the same for the same temperature, whether this space contains a gas or is a vacuum.*

2. *The pressure of the mixture equals the sum of the pressures which each would exert if it occupied the space alone.*

Spheroidal condition: The condition assumed by liquids when in contact with incandescent metal surfaces is known as the *spheroidal condition* (Fig. 48). Its remarkable phenomena were first observed a century ago. If a shallow metallic vessel is heated to a bright red and a small quantity of water thrown into it, instead of bursting into steam it quietly moves about on the surface, gathering itself up into a sphere, and gradually disappears. The assumption of this form is called the *spheroidal state*. Though seeming to be in contact with the metal, it is not, but floats about on a cushion of steam which bears it up. Rapid evaporation from its under-surface doubtless has a cooling effect, and if we could examine the temperature of the mass it is not at all improbable that it would be found quite cool.

FIG. 48.



Separation between globule and plate (Deschanel).

If the metal is a thin platinum capsule and we remove it from the source of heat, the temperature declines; and when it reaches a point when the elasticity of the steam cushion is not sufficient to support the water, it falls on the hot surface and is almost instantly dissipated as steam.

Density of vapors: The density of a vapor is the relation between its density and that of an equal volume of air or hydrogen at the same temperature and pressure. It may be determined in various ways. One method, that of Gay-Lussac, employs a graduated barometric tube of large size filled with mercury, into which a known weight of liquid can be introduced and completely vaporized. The volume of the vapor is shown by the graduation on the tube, and the pressure is obtained by subtracting the height of the mercury in the tube from the barometric height at the same time. Calculate the weight of a volume of air equal to that of the vapor under the same conditions of temperature and pressure. Divide the weight of the vapor by this ascertained weight of air, and the quotient will be the density.

Relation of density to molecular weights: It has been found that the densities of unsaturated vapors, like gases, are proportional to their molecular weights. Taking hydrogen, whose molecular weight is 2, as unity, then the density of an unsaturated vapor is half its molecular weight. If air is taken as unity, the density of hydrogen is $0.0693 = \frac{1}{28.86}$; and the density of all other gases and unsaturated vapors is $\frac{1}{28.86}$ of the molecular weight.

HYGROMETRY.

Province of hygrometry: The province of hygrometry is to determine the quantity of aqueous vapor contained in a given volume of air. The quantity is very variable in our climate, the air being seldom completely saturated, and never completely dry.

Hygrometric state: The ratio of the quantity actually present, to that which it would contain if saturated, is known as the *degree of saturation*, or *hygrometric state* of the air.

The weight of water actually present in the form of vapor in the unit of volume of atmosphere is known as the *absolute* moisture. The *apparent* dryness or moisture of the atmosphere does not depend on the absolute moisture, but on the degree of saturation, which, with the same amount of absolute moisture, is inversely as the temperature.

The *dew-point* is that temperature at which the air becomes saturated by the absolute moisture it contains, and deposits moisture on surrounding objects in the form of *dew*. If dew is deposited on objects whose temperature is below zero, it freezes, and is called *frost*. Moisture on an ice-pitcher is an example. The layers of air in contact with the pitcher are cooled till the moisture they contain saturates them and is deposited.

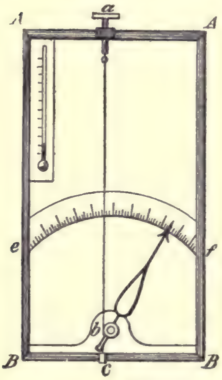
Hygrometers: There are two classes of instruments for measuring the amount of moisture in the atmosphere:

1. *Hygroscopes*, which simply show whether the air is moist or dry; and of which there are several examples.

2. *Hygrometers*, which determine accurately either the absolute moisture or the degree of saturation. These are either *chemical*, *condensing*, or *wet bulb*.

Hygroscopes: One form of this class is improperly termed *absorption hygrometers* (Fig. 49). These depend on the property possessed by organic substances of elongating when moist, and again contracting when dry. Some organic substance, such as a hair, fastened at one end, leads around a pulley to which is attached a needle moving over a scale. A small weight is fastened to the free end of the hair. Alterations in its length cause corresponding movements of the needle over the scale. The indications are never exact, and always behindhand. To this class belong various mantle-piece ornaments, which depend on the fact that twisted strands of catgut or string will untwist when moist, and *vice versa*. Another form depends on the property possessed by the chloride or nitrate of cobalt of changing color with different degrees of atmospheric saturation. A card or figure is colored with this substance, and changes color according to the weather.

FIG. 49.

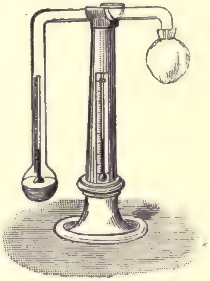


De Saussure's hygroscope (Deschanel).

Chemical hygrometers: By passing a known volume of air over some substance, such as chloride of calcium, which readily absorbs moisture, and weighing the substance both before and after, we can get the exact weight of the amount of aqueous vapor present in the air. Knowing the temperature, we can, by the use of tables, calculate the degree of saturation.

Condensing hygrometers: These are really *dew-point* hygrometers, and depend on the fact that, as a body gradually cools, the layer of air immediately surrounding it cools also, and deposits moisture on it when the temperature gets so low that saturation is reached. When the temperature again rises the moisture disappears. The mean of these two temperatures is the dew-point. Daniell's hygrometer (Fig. 50) is an example of this class. It consists of two bulbs at the ends of a bent glass-tube. Bulb *A* is partially filled with ether, and has inside it a thermometer. The rest of the space contains only vapor of ether. Bulb *B* is covered with muslin and ether is dropped upon it, thus gradually cooling *A*, as in the case of the cryophorus. The temperatures at which moisture is deposited on *A*, and at which it disappears, can be read from the thermometer, the mean being the dew-point. Dividing the tension of the air, at the time of the experiment, into the tension of air at the temperature of the dew-point, gives the degree of saturation. *Example:* If the temperature of the air at the time were 15° C., its tension if saturated would be 12.699 mm. The temperature of the dew-point was found to be 5° C., with a corresponding tension of 6.534 mm.; then $6.534 \div 12.699 = 0.514 = 51.40$ per cent. of saturation.

FIG. 50.



Daniell's hygrometer (Deschanel).

Wet-bulb hygrometers or psychrometers: These depend on the fact that moist bodies evaporate more rapidly in dried air than in moist, and that in consequence of such evaporation their temperature falls. Two thermometers are placed on a wooden stand, and the bulb of one is covered with muslin, which is kept constantly moist, being connected with a reservoir of water by means of a string. Unless the air is saturated, the wet-bulb thermometer always indicates a lower temperature than the other. The percentage of saturation is calculated from the readings of the two thermometers, by the use of tables.

Moisture of the atmosphere: The absolute moisture of the atmosphere varies continually with the temperature, and with the time of day or of the year, being greatest in the tropics. It is greatest in the hottest part of the day, when the relative moisture is least. The relative moisture in this country is less than in Europe, and evaporation, as a consequence, is far more rapid.

Fog is produced when a wave of cold air meets a humid current, and condenses its moisture into a visible form. *Rain* is produced by the condensation of minute drops in the clouds till those of greater size are attained, and rain falls.

TRANSMISSION OF HEAT.

Methods of transmission: Heat is transmitted from one body to another in two ways:

Conduction, which takes place through the means of an intervening body, which is itself heated. For example, when the end of a metal bar is heated, the rest of it becomes warm—*i. e.*, the heat is transmitted inward and warms the mass of the body itself. Good conductors are those which readily transmit heat, and bad conductors the opposite.

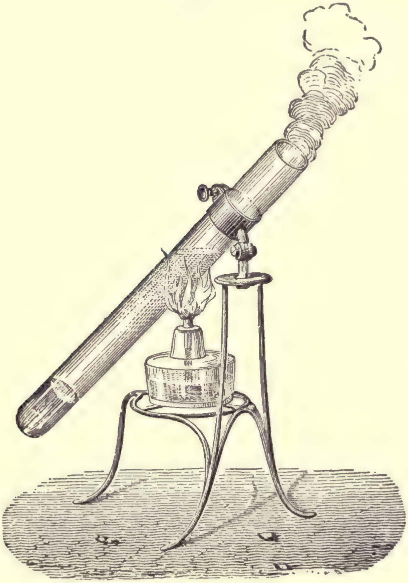
Radiation, in which process the intervening medium is not heated. For example, if we stand in front of a fire we feel its warmth. This is radiated to us through the air without warming it, as can be proved, for if we place a screen before the fire the sensation of heat instantly disappears, which would not be the case if the air itself were warm.

Conductivity of solids: Solids are the best conductors of heat, but the conductivity of different solids varies greatly. Metals are the best conductors, and at their head stands silver; while the resins, glass, wood, etc., are bad conductors. Water boils more rapidly in a metallic vessel than in a porcelain one of the same thickness. Taking the conductivity of silver as 100, that of copper is 73; gold, 53; iron, 12; and platinum, 8.

Clothing, to retain heat, should be of some non-conducting fabric, such as wool or silk. Linen and cotton, being comparatively good conductors, aid the escape of heat, and are called *cool*.

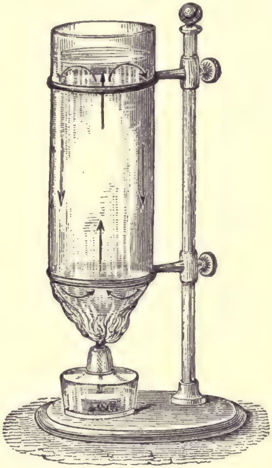
Conductivity of liquids: That liquids are very poor conductors may be shown by fastening a piece of ice in the bottom of a test-tube full of water (Fig. 51). Though the top layers of the water be brought to the boiling-point by the flame of an alcohol lamp held under them, the ice will still remain unmelted.

FIG. 51.



Boiling water over ice (Deschanel).

FIG. 52.



Liquid heated from below (Deschanel).

Convection is the process by which gases and liquids are heated. When a column of liquid is heated at the bottom, the inferior layers expand, become less dense, and rise, being replaced by colder denser layers (Fig. 52). In this way ascending and descending currents are produced. These may be made visible if we throw into the water wooden shavings, which rise and fall with them.

Conductivity of gases: It has been a disputed question whether gases have any conductivity. Certainly when their motion is restrained their conductivity is very slight. All substances between whose particles air remains stationary offer great resistance to the propagation of heat. It is for this reason that fur clothing is so warm, and that delicate plants may be protected from cold by packing straw around them. Heat is transmitted in gases, as in liquids, by *convection*.

Radiation of heat: Radiation is the sending out from heated bodies of rays which can excite heat and pass through air without heating it, just as rays of light penetrate transparent bodies.

We use the terms *ray of heat*, or *thermal* or *calorific ray* in a similar sense to that in which we use the term *ray of light* or *luminous ray.* The phenomena of radiant heat may be demonstrated by very delicate thermometers, or by the thermo-electric pile or battery.

Laws of radiation: The radiation of heat is governed by three laws, as follows :

1. *Radiation takes place in all directions round a body ;* as may be proved by placing a thermometer in different positions near a source ef heat.

2. *In a homogeneous medium radiation takes place in a straight line.* If a screen be placed between the source of heat and a thermometer, the latter will not be affected by the heat.

3. *Radiant heat is propagated in vacuo as well as in air.*

Intensity of radiant heat: By the *intensity of radiant heat* we mean the quantity of heat received on the unit of surface. The intensity has been found to be (1) proportional to the temperature of the source of heat ; (2) inversely as the square of the distance from the source ; and (3) the less, the greater the obliquity of the rays with respect to the radiating surface.

Theory of exchanges: Prevost suggested the following hypothesis, which is now generally admitted : All bodies, whatever their temperature, constantly radiate heat, so that the cooler of two neighboring bodies receives heat in excess from the warmer till their temperatures are equal. They then exchange only equal amounts of heat, and the temperature remains constant, a state known as the *mobile equilibrium of temperature.*

Reflection of heat: When thermal rays fall upon a body they are generally divided into three parts: one rebounds from the surface and is *reflected;* another penetrates it and is *absorbed;* while the third is irregularly reflected in all directions, or *diffused.*

Laws of reflection: Heat follows the same laws of reflection as govern light:

1. *The angle of reflection is equal to the angle of incidence.*
2. *Both the incident and the reflected ray are in the same plane with the normal to the reflecting surface.*

Reflecting power: The reflecting power of a substance is its capacity for throwing off a greater or less proportion of incident heat. It is inversely as the absorbing power, and almost exactly complementary to it. White or polished bodies reflect well, especially brass. A liquid will keep hot longer in a brightly polished metallic vessel than in a dull one. White lead is an exception to this rule. White clothing is cooler for summer, as it absorbs less of the sun's rays.

Absorbing power: This is the capacity of bodies for allowing more or less incident heat to pass into their mass, and is the reverse of the reflecting power. Dark-colored or dull substances absorb best. Lampblack and white-lead, which do not reflect any heat, will absorb almost all that falls upon them. Dark clothes are hotter in summer.

Radiating power: The radiating power of a body is its capacity for emitting a greater or less quantity of heat, and is identical with the absorbing power. Consequently, bodies which absorb well will radiate well. For this reason, stoves should be painted black, as they will then radiate more heat.

CALORIMETRY.

Quantity of heat: Heat acts on substances of the same size and temperature in different ways. Besides increasing their volumes unequally, it warms them unequally. If we take equal volumes of mercury and water and place them in front of a fire, the temperature of the former rises much more rapidly than that of the latter. If we use the same weights of the two substances, the difference is far more striking. From this we learn that *different bodies require different quantities of heat to warm them equally.*

In solids the same thing is evident. Take bullets of zinc and lead, and warm them equally by exposure to boiling water, giving them time to take up all the heat they will. Then drop them on a slab of wax about half an inch thick. The zinc melts its way through very quickly. The lead follows at a considerable interval. The heat held by the former is greater than that held by the latter.

Calorimetry: The object of calorimetry is to measure the quantity of heat a body parts with or absorbs when its temperature falls or rises through a certain number of degrees. Quantities of heat are most conveniently expressed by their effect in alteration of temperature.

The *thermal unit* is the quantity of heat required to raise the unit of a mass of water through the unit of temperature. According to Ganot, this is 1 pound avoirdupois of water through 1° C., though other units are used in different countries.

Specific heat: The specific heat of a body, known also as its *thermal* or *calorific capacity*, is the ratio between its capacity for heat and that of an equal weight of water. This varies in different substances, as only part of the heat which each body receives is devoted to raising its temperature by increasing the *vis viva* of its molecules, the rest being expended in the internal work of expansion and the external work of overcoming outside resistance. The portion devoted to raising temperature is sometimes called the *true specific heat*, or *true heat of temperature.*

Calorimeters: These are instruments for measuring the specific heat of a body just as the *intensity* of heat is measured by a thermometer. There are three forms of these instruments:

Method of the fusion of ice: This, the simplest method, employs a block of ice having a cavity, the mouth of which can be closed by a tightly fitting cover A substance of known weight, whose specific heat is to be estimated, is heated to a certain temperature and then placed in the cavity and covered.

When the substance is cooled to 0° C., it is removed and the water produced by the melting of the ice weighed. As it takes 80 heat-units to melt one pound of ice, we can readily calculate the number of heat-units given off by the substance. Dividing this by the product of its weight in pounds into its fall in temperature gives the specific heat. This is known as the *method of the fusion of ice.*

Method of mixtures: A body of known weight is heated to a certain temperature and then plunged into water whose temperature and quantity are known. The specific heat is similarly calculated from the subsequent rise in temperature of the water.

Method of cooling: This depends on the fact that different substances under similar conditions occupy different times in cooling through the same number of degrees of temperature. The time taken has been found to vary directly as the specific heat.

Specific heat of solids and liquids: Any of these three methods may be used for determining the specific heat of solids or liquids; though, in the case of solids, the method of cooling is inaccurate.

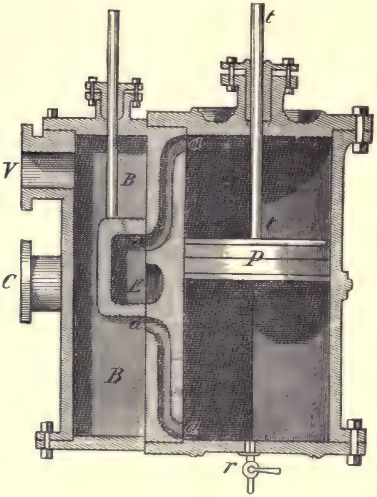
Specific heat of gases: Either water or air may be used as the unit in determining the specific heat of gases. In the former case it is the ratio of the quantities of heat required to raise equal *weights* of water and the gas through 1° C.; while in the latter it is the ratio between equal *volumes* of air and the gas, under equal pressures. In either case it is determined by passing a known weight of the gas or known volumes of the gas and air, the temperature being known, through a long, spiral tube placed in water, and calculating the specific gravity from the increase in temperature of the water.

Laws of specific heat: These are three in number:

1. *Every substance has its own specific heat, and this increases with the temperature;*
2. *This increase is greater in liquids than solids, except in the case of water;*
3. *The same quantity of heat is needed to heat an atom of all simple bodies to the same extent.*

This latter, known as *Dulong and Petit's law*, has been proved by experiment to be practically true, making due allowance for errors of manipulation. Consequently the specific heat of a body may be obtained by dividing its atomic weight by the *atomic heat*, which is the quantity of heat required to raise the temperature of the same number of atoms of different substances by one degree. This atomic heat is not yet exactly known, but is probably about 6.4, except in the case of a few elements. The results of this method agree very closely with results obtained in other ways.

Fig. 53.



Cylinder and connection (Deschanel).

Steam engines: Steam engines are machines by which the effects of heat are turned into mechanical work, aqueous vapor being used as the means of transformation. As generally constructed, the heat of combustion is imparted to water in a closed container, known as the boiler. The water is thereby converted into steam, occupying an enormously greater volume, and this steam is allowed to pass from the boiler as fast as it forms, and to act alternately on the two sides of a movable piston, working backward and forward in a cylinder (Fig. 53).

The elastic force of the steam causes the piston to move. When the incoming steam has pushed the piston to one end of the cylinder, by acting on one side of it, communication between that side and the boiler is shut off, and the steam is allowed to escape, while communication is opened between the boiler and the other side of the piston. The resultant backward and forward motion of the piston-rod is converted by mechanical devices into circular motion of a crank or wheel, and thus made to move machinery.

Varieties of steam-engines: There are two kinds of steam-engines, known as the *condensing* and the *non-condensing engine.* In a condensing engine the steam, after lifting the piston, is not allowed to escape into the atmosphere, which would resist its egress at the rate of 15 pounds per square inch, but is conducted to a condensing-chamber, from which, after being condensed, it is pumped back to the boiler. This last process creates a partial vacuum, and therefore lessens the pressure which the utilized steam must resist. The non-condensing engine does not condense its steam, but allows it to escape against the atmospheric pressure.

The condensing engines are, in general, the more economical. Formerly engines were termed *low-* and *high*-pressure engines.

Compound engines are condensing engines in which the steam is first used in one cylinder in the ordinary way, and then transferred—at a comparatively low pressure—to another large cylinder, and used in it before being transferred to the condenser.

Other forms of engines: Hot-air or explosive gases, such as naphtha, are frequently employed to furnish the medium for transferrence of energy to the piston when space and convenience are to be considered. They are more economical for small engines.

SOURCES OF HEAT AND COLD.

Sources of heat: The various sources of heat are:

1. *Mechanical*, comprising friction, percussion, and pressure;

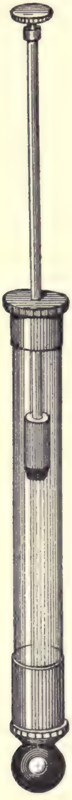
2. *Physical*, comprising solar radiation, terrestrial heat, molecular changes, change of condition, and electricity;

3. *Chemical*, or molecular combinations, and more especially combustion.

Friction: The friction of two bodies, one against the other, produces heat which is directly as the pressure and the rapidity of motion. The savage creates a fire by rubbing two pieces of wood together. The metallic axles of carriage-wheels often become so strongly heated by friction as to expand and jam.

Pressure: If a body is so compressed that its density is increased, the temperature rises accordingly as the volume diminishes. This can easily be shown in the case of gases. The air compressed suddenly in a pneumatic syringe (Fig. 54) becomes hot enough to ignite a piece of cotton saturated with ether and placed inside it.

Fig. 54.



Fire-syringe (Deschanel).

Percussion: The amount of heat produced in this way depends on the momentum. In firing shot at an iron target, a sheet of flame is often seen at the moment of impact. A small piece of lead hammered on the anvil becomes very hot, not from increased density, but because of the vibratory movement imparted to its molecules, the density of lead not being increased by hammering.

Solar radiation: The sun is the most intense of all sources of heat. It has been calculated that the earth receives enough heat from the sun in the course of a year to melt a layer of ice 35 yards thick all around the earth. The origin of this heat is a subject of conjecture, but condensation is probably the best explanation.

Terrestrial heat: Our globe possesses a heat peculiar to itself, known as terrestrial heat, and supposed to be produced by its internal molten mass. Below the limit to which solar heat can penetrate, known as the *layer of constant annual temperature*, terrestrial heat increases on the average 1° F. for every 50 feet of depth.

Molecular phenomena: Absorption, capillary action, etc., are usually accompanied by the disengagement of heat. When a jet of hydrogen gas is directed on spongy platinum, the absorption of the gas by the metal produces enough heat to set the hydrogen on fire.

Change of condition: We have already spoken of the heat disengaged during solidification of liquids or liquefaction of gases.

Electricity: That heat is produced by electrical action will be shown in the description of electricity.

Chemical combination: An elevation in temperature usually accompanies all chemical combinations. If the combination takes place slowly, as when iron oxidizes in air, the heat produced is imperceptible; but if the combination is rapid the heat is often intense. In both cases the same amount of heat is produced. When bodies attract each other chemically their molecules move toward one another with gradually increasing velocity; they meet and, at the impact, their progressive motion is transformed to a vibratory motion of the molecules of the new body, expressed as *heat.* Thus motion is transformed into heat.

Combustion: By this term is meant chemical combination accompanied by the evolution of light and heat. Though the substance usually combines with the oxygen of the atmosphere, the presence of oxygen is not requisite for all forms of combustion. The *flame* of combustion is a gas or vapor raised to a high temperature during the process; while the presence of a solid body in this flame increases its illuminating power. The flames of hydrogen and alcohol are pale, as they contain only gaseous products of combustion; but the flames of candles, gas-jets, etc., are bright, because of the presence of particles of carbon which, being at first unburnt, become incandescent. The temperature of a flame does not depend on its illuminating-power.

Decomposition, the reverse of chemical combination, requires an expenditure of heat or work to overcome molecular attraction, heat being transformed to motion.

Animal heat: Oxidation is continually going on in the organs of all forms of animal life, producing heat and motion. The amount of oxidation, and its resultant heat, vary in different animals. Oxygen is absorbed in the lungs by the blood, and carried by it to oxidizable bodies, chiefly hydrocarbons, which we received from the products of digestion. The blood also distributes the heat uniformly throughout the body. Life is only permissible because of the heat produced in this way.

Heating: The art of utilizing for various purposes the heat produced by combustion is known as *heating*. We distinguish five kinds of heating according to the apparatus used: 1, heating with an open fire; 2, with an enclosed fire, as with a stove; 3, by hot air; 4, by steam; 5, by the circulation of hot water.

Sources of cold: The sources of cold are:

1. *Change of state*, as shown in the passage of a body from the solid to the liquid state.

2. *Expansion of gases.* When a gas is compressed the temperature rises, but when it again expands cold is produced, as heat is absorbed by the increase of volume, and the consequent increase in molecular activity. Ice machines are made, depending on this principle. Air or gas is first compressed, producing heat. It is then cooled, and allowed to expand, producing great cold.

3. *Radiation.* The earth is constantly losing heat by radiation. During the day this process is neutralized, as it receives more heat from the sun than it loses by radiation, and the temperature rises; but at night the reverse is the case, and temperature falls, more especially on a clear night than on a cloudy one. In warm countries this nocturnal cooling is used in manufacturing ice. Flat vessels containing water are placed on some non-conducting substance, such as straw. In consequence of radiation the water will freeze, even when the temperature of the air is 40° F., provided the sky is clear.

Mechanical equivalent of heat: Mechanical force is consumed in all forms of the production of heat by motion. When two bodies are rubbed together, or when a body falls from a height to the ground, motion is not destroyed, but is transferred into molecular activity expressed as heat. Conversely, heat may be made to produce motion, as in the steam-engine. It has been found that a definite amount of mechanical work will produce a definite amount of heat. If this heat can be perfectly converted, it will produce the original amount of mechanical work. Joule established the fact that the heat required to raise 1 pound of water through 1° F. would, when converted into motion, raise a weight of 772 pounds through a height of 1 foot, or 1 pound through 772 feet. The same amount of heat would be produced by a pound weight falling 772 feet. In other words, 1 thermal unit is the equivalent of 772 foot-pounds of mechanical energy.

LIGHT.

Theories of light: *Light* is the agent which, by its action on the retina, excites in us the sensation of vision. That part of physics which deals with the properties of light is known as *Optics.* The two principal theories in regard to the origin of light are the *emission*, or *corpuscular*, and the *undulatory* theory.

Theory of emission: This assumes that luminous bodies emit, in all directions, an imponderable substance, consisting of molecules of an extreme degree of tenuity, which are propagated in right lines with inconceivable velocity. Penetrating the eye, they fall upon the retina and produce the sensation of vision.

Theory of undulation: This assumes that all bodies, as well as the celestial spaces, are filled with an extremely subtle elastic medium, known as the *luminiferous ether.* The luminosity of a body, due to an infinitely rapid vibratory movement of its molecules, when communicated to this ether sets up in it rapid vibrations, which are propagated in all directions in the form of spherical waves. This vibratory motion, when transmitted to the retina, produces the sensation of vision. There is no progressive motion of the particles of the ether, but merely an oscillation in *transversal* vibrations, at right angles to the waves of light. An idea of these may be formed by shaking a rope at one end: though the wave-like motion of the rope progresses toward its end, the vibrations of particles of the rope are transversal. This theory is generally adopted, as it explains and harmonizes many of the phenomena of light, and reveals an intimate connection between them and those of heat. It shows how analogous are the phenomena of light and sound. Heat and light are supposed to differ only in the length of their waves.

Definitions: *Luminous bodies* are those which emit light, such as the sun or ignited bodies.

Transparent bodies are those which readily transmit light, and through which objects can be distinguished, such as glass, air, water, etc.

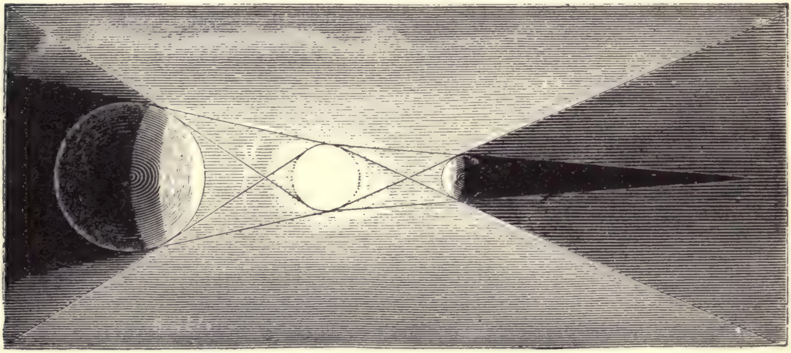
Translucent bodies transmit light, but objects cannot be distinguished through them. Among these are ground glass, oiled paper, etc.

Opaque bodies do not transmit light—*i. e.*, woods, metal, etc, No bodies are perfectly opaque, as all become more or less translucent if cut in sufficiently thin layers.

A *luminous ray* is merely the direction in which light is propagated, having but one dimension.

A *luminous pencil* is a collection of rays from the same source. These rays may be parallel, divergent or convergent. Every pencil has three dimensions. Every luminous body emits divergent rectilinear rays in all directions.

FIG. 55.



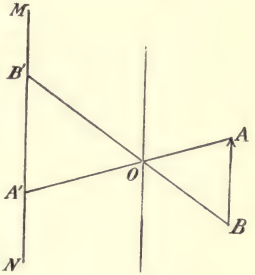
Umbra and penumbra (Deschanel).

A *medium* is any space or substance through which light can travel, as air, water, or a vacuum. In every homogeneous medium light is propagated in a right line.

A *shadow* is produced when light falls upon an opaque body, as the space immediately behind it, not being penetrated by the light, is not illuminated. As light never comes from an exact point, there is a portion of the margin of the shadow somewhat brighter than the rest, as it is partially illuminated. This is known as the *penumbra* (Fig. 55).

Images produced by small apertures: When luminous rays pass into a dark chamber through a small aperture and are received upon a screen, they form images of the external objects from which they come. These images are inverted and their shape is that of the external object, no matter what the shape of the aperture (Fig. 56). The inversion occurs because the rays of light, coming from different parts of the objects, cross each other at the aperture. In Fig. 56 the ray *A O* from *A* crosses the ray *B O* from *B*, and *A* is reproduced at *A′*, while *B* is reproduced at *B′*, on the screen *M N*.

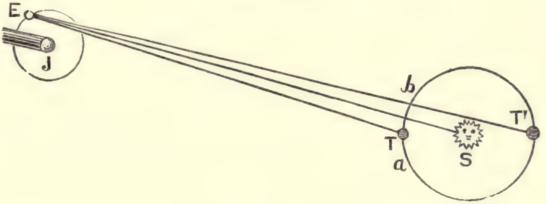
FIG. 56.



Velocity of light: Light moves so rapidly that, to ordinary observation, we seem to see things instantaneously.

The first determination of the velocity of light was made by Roemer, a Danish astronomer, in 1675. The method employed was by the observation of Jupiter's satellites. The first satellite, *E* (Fig. 57), is occulted or passes behind the planet *J* at equal periods of about forty-two and a half hours. When the earth passes from *a* to *b*, on the side of its orbit nearest to Jupiter, there is but little difference in its distance from day to day, and, therefore, but little variation between two occulta-

FIG. 57.



Velocity of light.

tions. When, on the contrary, the earth in its revolution around the sun passes from T to T' on the opposite side of its orbit, it is found that there has been a total retardation of the actual from the calculated time of occultation of about sixteen and a half minutes. This represents the time required for the light to pass from one to the other side of the earth's orbit. Taking the earth's distance from the sun at 95,000,000 miles, Roemer computed the velocity of light at 190,000 miles per second. At the modern estimate of 91,500,000 miles for the sun's distance from the earth, the rate is 185,000 miles per second.

In water light moves with a speed about three-fourths as great. In general, the denser the medium the slower the rate.

Laws of intensity of light: The intensity of illumination is the quantity of light received on the unit of surface. It has been found to be subject to the following laws:

1. *The intensity of illumination on a given surface is inversely as the square of its distance from the source of light;*

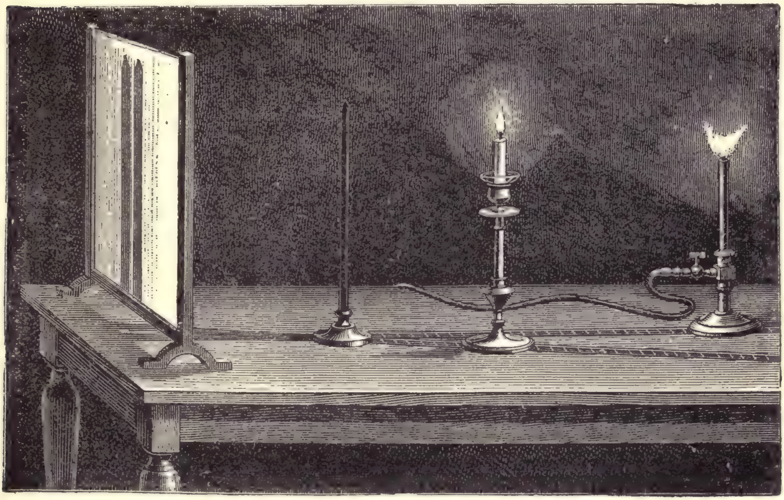
2. *The intensity of light falling obliquely is inversely proportional to the angle of incidence.*

The eye cannot accurately measure the relative intensity of illumination of surfaces which are unequally lighted; but the first law may be verified by showing that the illumination produced on a given surface by one candle at a given distance is equal to that produced by four candles at a distance twice as great. The second law corresponds to the law which prevails for heat, and may be deduced theoretically.

Photometers: Photometry is the measurement of the relative amounts of light emitted from different sources.

Fig. 58 is an example of an apparatus designed for this purpose. The standard light and the light to be tested are placed at such distances from an opaque rod that the two shadows cast by it on a ground-glass screen are of equal intensity. The intensities of the two lights, being directly as the squares of their distances from the shadow, can then be calculated. The *standard light* is usually a candle of certain size which burns a certain number of grains per hour, but it varies in different countries. Other photometers depend on the illumination of opposite sides of a greased spot on a piece of paper. When placed between two lights, the spot appears darker than the surrounding paper on the side which receives the most light, and *vice versa*. The paper is moved between the lights till the spot and the rest of the paper appear alike. The intensities of the two lights are then calculated, as before, from their distance from the paper. Bunsen's photometer is of this kind.

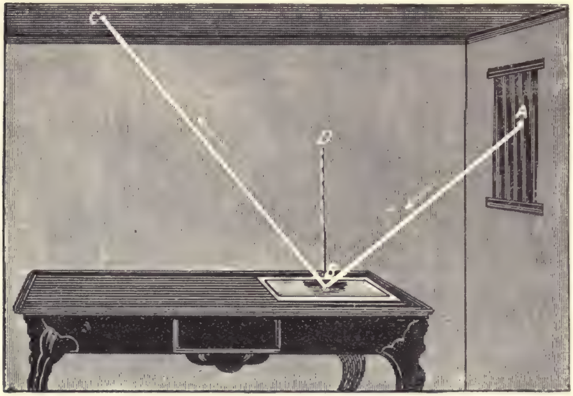
FIG. 58



Rumford's photometer (Deschanel).

Reflection of light: When a ray of light meets a polished surface it is reflected just as rays of heat are reflected, and this reflection follows the same laws. The angle of reflection is equal to the angle of incidence, and both the incident and the reflected ray are in the same plane, which is perpendicular to the reflecting surface. In Fig. 59, a ray of light admitted through a hole, *A*, in a shutter falls upon a mirror at *B*, and is reflected. *A B* is the *incident* ray; *B C* is the *reflected* ray. The angle, *A B D*, between the ray and the vertical line *B D* is the *angle of incidence;* while *C B D* is the *angle of reflection.* The plane *A B D* is the *plane of incidence.*

FIG. 59.



Reflection of light (Deschanel).

Mirrors: Bodies with polished surfaces which reflect objects presented to them are known as *mirrors.* The place at which objects appear is their *image.* Mirrors are classed, according to the shape of their reflecting surface, as *plane, convex, concave, spherical,* etc. Unpolished surfaces scatter or diffuse light because the irregularities of their surfaces correspond each to minute mirrors, facing in different directions and reflecting the rays of light accordingly.

Plane mirrors: The determination of the position and size of images resolves itself into investigating the images of a series of points. In Fig. 60, a divergent pencil of light proceeds from a luminous point at the top of a candle-flame, *A*, and is reflected from the mirror at *B*. After reflection the rays on entering the eye have the same divergence as when they impinged upon the mirror, and if produced backward meet at a point, *C*, which is the position of the image of the top of the flame. In like manner, every point appears in its proper position, and a complete image is observed.

The images produced by plane mirrors are *erect images*, but they are not exact duplicates of the objects, since they differ from them exactly as the right hand differs from the left. This may be readily seen if we examine the reflected image of a page of print in a mirror, when it appears as if viewed through the back of the page, or like the surface of the type from which it was printed. The image seems as far behind the mirror as the object is in front of it, and is of the same size.

FIG. 60.

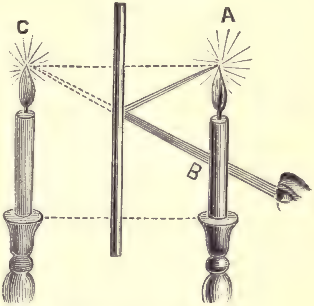
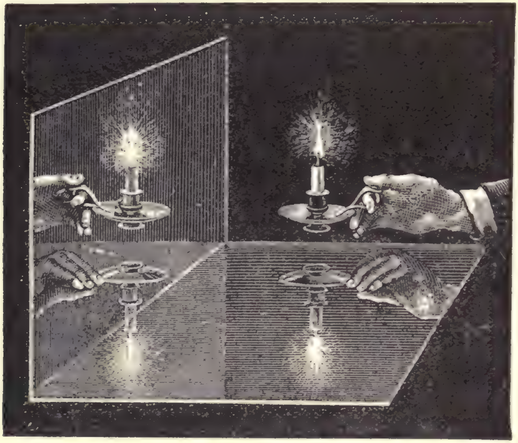


Image in plane-mirror.

Virtual and real images: The image in the preceding illustration is only a **virtual** one, as the eye is deceived, the luminous rays which apparently come from the opposite side of the mirror being imaginary. All images produced by *plane* mirrors are virtual or imaginary; while in the case of *concave* mirrors, where the reflected rays converge in front of the mirror, the image is a *real* one, as it can be received on a screen. We can, therefore, say that virtual images are those formed by prolongations of light rays, while real images are those formed by the rays themselves.

Multiple images: Metallic mirrors which have but one reflecting surface give only one image. Glass mirrors have two reflecting surfaces, the surface of the glass in front and the metallic surface at the back of the mirror. When the image of a candle is looked at obliquely in a mirror, a very distinct image is seen reflected from the metallic surface and a very feeble one reflected from the glass surface. When an object is placed between two plane mirrors which form an angle with each other, either right or acute, images are formed which increase in number with the inclination of the mirrors. If they are at right angles, three images are seen (Fig. 61). The *kaleidoscope* depends on this property. It consists of three plane mirrors set at an angle of 60° inside a tube. In one end of the tube is an eyehole, while the other is closed by two plates of glass, one of which is ground, between which are irregular bits of colored glass. The images are seen arranged in beautiful symmetrical forms. In the case of an object placed between two parallel plane mirrors, the number of images is theoretically infinite; but practically the images gradually fade away and disappear as light is absorbed.

FIG. 61.



Mirrors at right angles (Deschanel).

Curved mirrors: These reflect light in a way that can readily be understood if we suppose that their surfaces are made up of an infinite number of small plane surfaces, known as its *elements*. The angle of reflection of any ray from one of these elements is equal to its angle of incidence.

Spherical mirrors: These are mirrors whose curvature is that of a sphere. Their surface may represent any part of the arc of a circle, and they are either *concave* or *convex*, according as the reflection takes place from their internal or external surface. In Fig. 62, the centre, C, of the hollow sphere, of which the mirror MN forms part, is called the *centre of curvature*.

The point *O* is the *vertex* or centre of the mirror. The infinite right line *O C* passing through *O* and *C* is the *principal axis.* Any other straight line between *C* and the mirror, as *C I*, is a *secondary axis.* The angle *M C N* is the *aperture* of the mirror. The *focus* is the point at which reflected rays meet, as at *F.* The focus may be either *real* or *virtual.* It is real if these rays meet or tend to meet if produced on the same side; virtual if they do so only when prolonged on the opposite side of the mirror.

FIG. 62.

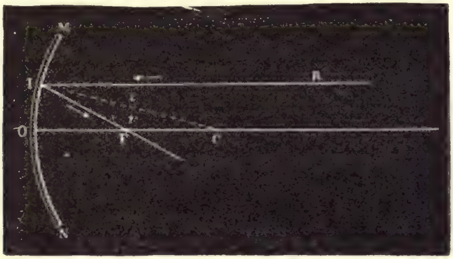
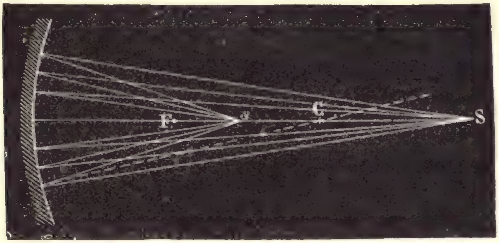


FIG. 63.



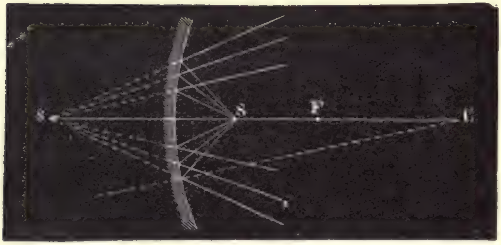
Conjugate foci (Deschanel).

Real focus of a spherical concave mirror: When the rays of light falling on the mirror are parallel to the principal axis, as in Fig. 62, the focus is at a point, *F*, equidistant from the mirror and the centre of curvature, and is known as the *principal focus ;* while the distance $O\ F$ is known as the *principal focal distance.* Rays of light coming from an infinite distance are practically parallel. Conversely, rays from a light placed at the point F are reflected in parallel lines, $O\ C$, $I\ R$, etc.

If, as in Fig. 63, the rays are emitted from a luminous point, S, placed on the principal axis, they will be divergent instead of parallel ; and will meet, when reflected, at some point, as s, situated between the principal focus and the centre of curvature. Such a point is known as a **conjugate focus,** because if the light were at s the focus would be at S.

Virtual focus of a spherical concave mirror : If the point of light is placed at S, between the principal focus and the mirror, as in Fig. 64, we will find that the reflected rays are divergent,

FIG. 64.



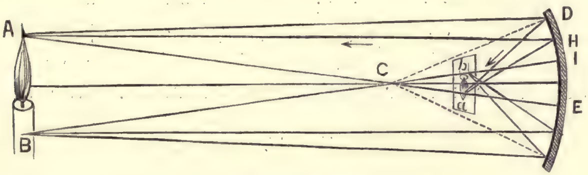
Virtual focus (Deschanel).

and do not intersect unless we imagine them prolonged on the other side of the mirror. When prolonged, they will meet at some point, as s, known as a *virtual* focus, because it is imaginary, analogous to the virtual image formed by a plane-mirror. Hence we see that the principal and the conjugate foci are always on the same side of the mirror as the luminous object and are real ; while the virtual focus is always on the opposite side. All these observations will apply equally well when the luminous point is not placed on the principal axis.

Foci of convex mirrors : The foci of convex mirrors are all virtual, as all incident rays diverge from their surfaces after reflection. The converging point, behind such a mirror, of the prolongation of the reflections of parallel rays falling on it, is known as the *principal virtual focus.* If the rays come from a point on the axis at a finite distance, the virtual focus will be on the axis at a point nearer the mirror than the principal focus.

Images of concave mirrors: The images, as the foci, may be either real or virtual, First, take the case where the object is farther from the mirror than its centre of curvature, but on the principal axis, as in Fig. 65. As an image is a series of points, a focus but one point, conjugate foci of all points between *A* and *B* will be formed between *a* and *b*, and thus between *a* and *b* an image of *A B* will be formed. The image is in front of the mirror, it is upside down, and is smaller than *A B*. Thus, *in concave mirrors, where the object is beyond the centre of curvature, an image will be formed between the centre of curvature and the principal focus, and the image is real, inverted, and smaller than the object.*

Fig. 65.

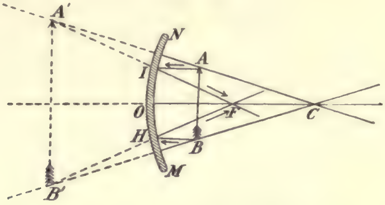


Real image (Draper).

Suppose the object were at an infinite distance, the image would be at the principal focus. As the object approaches the centre of curvature, the image moves outward from the principal focus toward the centre. If the object were at the centre, the image would coincide with it. If it were between the centre of curvature and the principal focus, as at *a b*, the image would be formed outside the centre, as at *A B*, and would be *real, inverted, and larger than the object.*

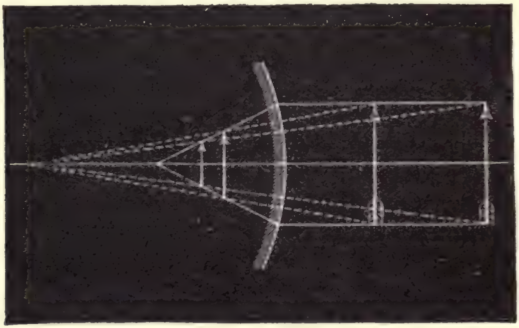
Secondly, suppose the object were between the mirror and the principal focus, as in Fig. 66. The object, *A B*, would produce, by prolongations of its reflected rays, the image $A' B'$. *This image is virtual, erect, and larger than the object.*

FIG. 66.



Images of convex mirrors: The images of convex mirrors, like their foci, are always virtual. They are also erect and smaller than the object. In Fig. 67 two objects are placed in front of such a mirror at different distances. We can see, from what has already been stated, that virtual images will be formed from the prolongations of the reflections of the divergent rays, *virtual, erect, and smaller than the objects.*

FIG. 67.

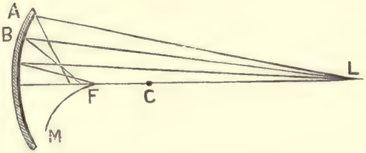


Formation of image in convex mirror (Deschanel).

Spherical aberration: It has been found that spherical mirrors do not follow these preceding examples exactly if they are of large size.

For arcs of more than 10° there are deviations: The exterior rays reach a focus nearer to the mirror than those reflected from the regions nearer the pole, as at *B*, and the image is blurred. To this effect and its cause the term *spherical aberration* is applied. It is represented in Fig. 68, where the ray from *L*, reflected from *A*, cuts the principal axis within the point at which the ray reflected from *B* reaches it. By connecting these points of intersection, the curve *M F* is obtained. This is called the *caustic*. It is perceivable when lamp-light or candle-light is reflected from the interior of a tumbler upon milk or other fluid contained therein.

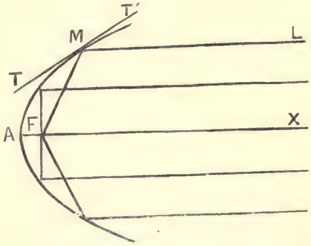
FIG. 68.



Spherical aberration (Draper).

Parabolic mirrors: Spherical aberration is overcome by using mirrors which have the curve of a parabola instead of that of a sphere. Fig. 69 indicates that in a parabola if any straight line, *F M*, be drawn from the focus to any point, *M*, and there meet a line, *M L*, parallel to the axis, the two lines will form equal angles with a tangent, *T T′*, to the curve at their point of intersection, *M*. From this it follows that all rays parallel to the axis will be reflected to the focus; and, conversely, a luminous point at the focus will give parallel rays. Hence the use of these in railway and carriage reflectors.

FIG. 69.



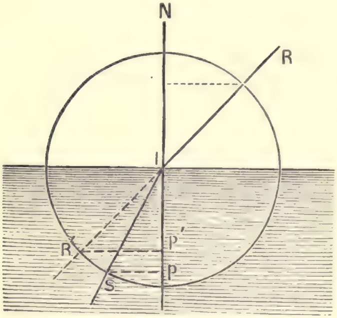
Parabolic mirror.

SINGLE REFRACTION.

Phenomena of refraction: By refraction we mean the change of direction which light undergoes when passing obliquely through different media. If a ray of light strikes parallel surfaces perpendicularly, there is no deviation in its direction. Its course is a straight line, and there is no refraction.

The *incident ray*, Fig. 70, being represented by *R I*, the *refracted ray* is the direction, *I S*, which the light takes in the second medium. Of the angles which these rays form with the line *N P*, at right angles to the surfaces, the upper one, *N I R*, is the *angle of incidence* and the lower one, *S I P*, the *angle of refraction*. In uncrystallized media the luminous ray is singly refracted; but in certain crystallized bodies, such as Iceland spar, it gives rise to two refracted rays, the phenomena being called *double refraction.*

Fig. 70.



Laws of single refraction: The laws governing the refraction of a luminous ray when passing from one medium into another of different refractive power are:

1. *The ratio of the size of the angle of incidence to the size of the angle of refraction is constant for the same two media, but varies with different media;*

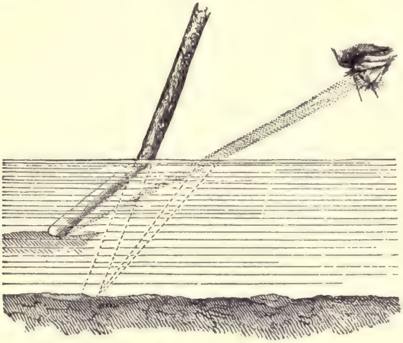
2. *The incident and refracted rays are in the same plane perpendicular to the surface separating the media.*

Index of refraction: The ratio between the sizes of the incident and the refracted angle is called the *index of refraction.* It varies with the medium. From air to water it is $\frac{4}{3}$, and from air to glass it is $\frac{3}{2}$, and *vice versa.*

Effects of refraction: A body immersed in a medium more highly refractive than air appears nearer the surface. A stick plunged obliquely in water appears bent toward the surface

(Fig. 71). Owing to the refraction of the layers of air, stars are visible when below the horizon.

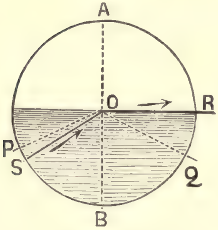
FIG. 71.



Appearance of stick in water.

Total reflection—critical angle: When a luminous ray passes into a medium of less refracting power, as from water to air, the angle of incidence is less than the angle of refraction. Hence, there is always an angle of incidence, *S O B*, such that the angle of refraction, *A O R*, is a right angle and the refracted rays emerge parallel with the surface. It is called the *critical angle* (Fig. 72), since at any greater angle, *P O B*, the incident ray cannot emerge, but undergoes *total reflection*, being entirely reflected in the line *O Q*. Bubbles in water glisten like pearls because the oblique rays, falling on them, are totally reflected.

FIG. 72.

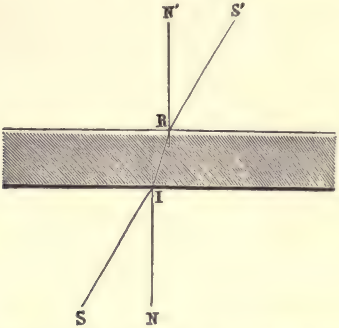


Critical angle.

Mirage: This is an optical delusion by which inverted images of distant objects are seen as if below the ground or in the atmosphere. It is a phenomenon of refraction which results from the unequal density of different layers of the air. The rays from an object are bent more and more, till they fall so obliquely on some layers that they are totally reflected, and thus reach the eye of an observer.

Media with parallel faces: When light traverses a medium with parallel faces (Fig. 73), the *emergent* rays are parallel to the incident ones, the distance between them being proportional to the thickness of the medium and increasing with the obliquity of incidence as well as with the index of refraction. Objects seen obliquely through a plate of glass are accordingly displaced laterally.

Fig. 73.



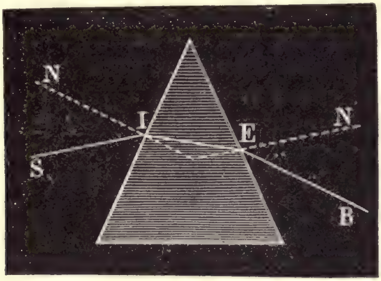
Medium with parallel faces (Deschanel).

Prisms: A prism is any transparent medium compressed between two plane faces inclined to each other. The intersection of these two faces is the *edge* of the prism, and their inclination is its refracting angle. Every section perpendicular to the edge is called a *principal section*. In experiments a right triangular prism is generally used whose principal section is a right triangle. The apex of the section, corresponding to the edge of the prism, is called the *summit*, and the right line opposite is called the *base*.

Path of rays in prisms: Knowing the laws of refraction, we can readily determine the path of rays in a prism. In Fig. 74, let $S I$ be an incident ray from the luminous point, S, in the same plane as the principal section, falling on the prism at I. As the ray passes into a more highly refracting medium it approaches the normal, $N N'$, and takes the direction $I E$. At

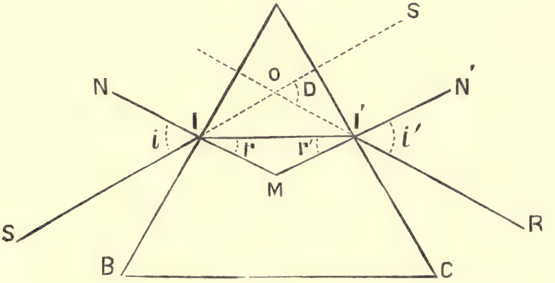
E it is again refracted, deviating from the normal as it passes to a less highly refracting medium, the air. The ray is thus refracted twice in the same direction, and is *deflected toward the base.* Consequently objects seen through a prism appear deflected toward its summit. The angle between the incident and emergent rays is called the *angle of deviation.* This angle increases with the refractive index of the material composing the prism and with its refracting angle.

Fig. 74.



Refraction through prism (Deschanel).

Fig. 75.



Prism.

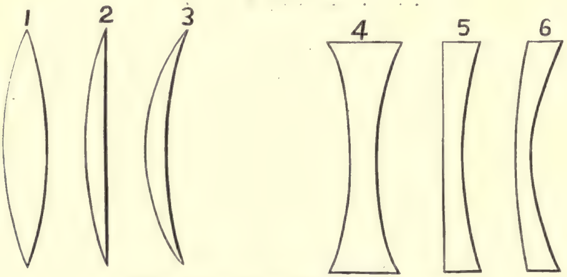
Cause of refraction in a prism: It is due to the relative velocity of light in the two media. The velocity of light is greater in air than in glass. Retardation of a wave of ether striking *S I* (Fig. 75) at *I* begins at the lower side and progresses until the whole wave-front enters the glass. This causes a change of direction maintained by the ray until it reaches the next face, *I′*, at which place it is for similar reasons again refracted.

Effects of a prism on light: Besides refracting the ray of light, a prism causes objects seen through it to appear in all the colors of the rainbow, a phenomenon known as *dispersion*. It does this by separating the beam of light into its constituent rays, which are colored. It also partly separates heat-producing rays from those producing light.

Lenses: These are transparent media, which, from the curvature of their surfaces, cause the luminous rays passing through them to converge or diverge. According to their curvature, they are *spherical*, *cylindrical*, etc. Those used in optics are always spherical.

Varieties of spherical lenses: By combining spherical with plane surfaces, or with each other, we get six kinds of spherical lenses. Lenses whose edges are thinner than their middle are called *converging* or *convex*, and those whose middle is thinner are called *diverging* or *concave* (Fig. 76).

FIG. 76.



Forms of convex and concave lenses.

(1) Double convex lens: bounded by two convex faces whose radii are in opposite directions and overlapping;

(2) Plano-convex lens: bounded by a plane and a convex surface;

(3) Converging concavo-convex: having one face concave and the other convex, but both converging;

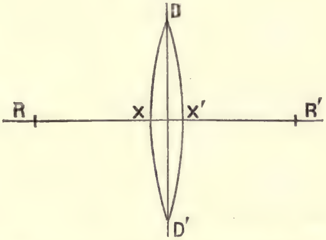
(4) Double concave lens: both faces concave;

(5) Plano-concave lens: one face plane, the other concave;

(6) Diverging concavo-convex: one face concave, the other convex, but both diverging.

Principal parts of a lens: In a lens whose two surfaces are spherical, as in Fig. 77, the line *R X′*, by which the curve *D X′ D′* is described, is its *radius of curvature*, and the point on which the radius revolves is the *centre of curvature;* on the opposite side the centre of curvature for *D X D′* is found in a similar manner.

FIG. 77.



Forms of convex and concave lens.

A line connecting the two centres, and piercing the lens at *X X′*, is the *principal axis* of the lens. Where one surface is plane, the principal axis is the line let fall from the centre of curvature of the spherical face perpendicularly upon the plane face.

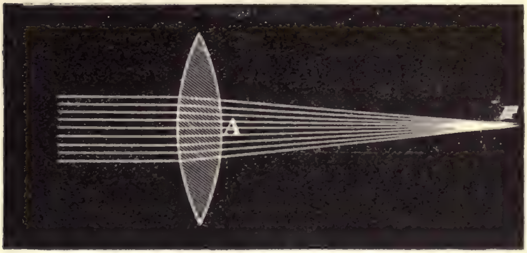
The line *D D′*, drawn from one point of the circumference to that exactly opposite, is called the *diameter*. The axis and diameter are perpendicular to each other.

The *aperture* of a lens is the angle between lines connecting the extremities of a diameter with the principal focus.

Path of luminous rays through a lens: By regarding the curved surface of a lens, like that of a curved mirror, as being made up of an infinite number of small plane surfaces, we can see that the first three kinds of lenses are made up of a series of prisms with their summits outward—*i. e.*, directed toward the circumference; while in the last three the summits are inward. In the first class, therefore, rays are condensed, being deflected toward the bases of the prisms—*i. e.*, toward the principal axis of the lens; while they are scattered in the second class, the concave lenses.

Foci of double convex lenses: The *focus* of a lens is the point where the refracted rays or their prolongations meet. Convex lenses, like concave mirrors, have both real and virtual foci.

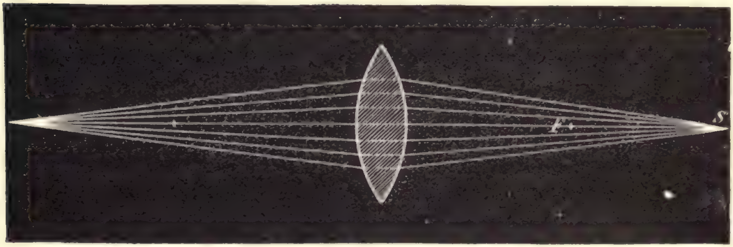
FIG. 78.



Principal focus of convex lens.

Real focus: When parallel rays fall on a double convex lens they converge, as in Fig. 78, at a point, *F*, known as the *principal focus*. The distance, *F A*, is the *principal focal distance.* When the radii of the two surfaces are equal the principal focus coincides very closely with the centre of curvature. Again, if the rays come from a luminous point, *S*, outside of

FIG. 79.

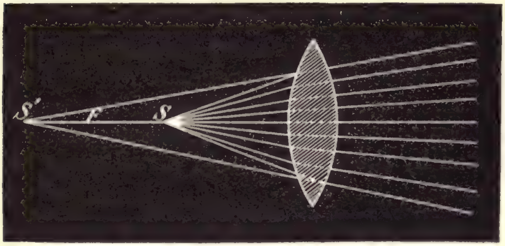


Conjugate foci, both real.

the principal focus, as in Fig. 79, they will converge at a point, *S;* these two points being known as conjugate foci. All these foci are *real.*

Virtual focus: If a luminous point, *S*, is between the lens and its principal focus, all the emergent rays will diverge, and, as in the case of a concave mirror, we get only a virtual focus, *S′* (Fig. 80).

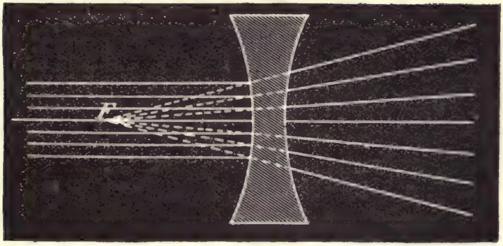
FIG. 80.



Conjugate foci: one real, one virtual.

Foci of double concave lenses: With these lenses we can get only virtual foci. As we suppose such lenses to be made of prisms with their bases outward, and as prisms deflect light toward their bases, all rays of light passing through such

FIG. 81.



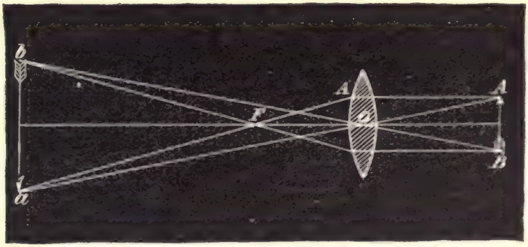
Principal focus of concave lens.

lenses are deflected from their principal axes, as in Fig. 81, and can never form a real focus.

Optical centre : In every lens there is a point so situated that rays of light passing through it have no angular deviation. This is known as the *optical centre,* and lies in the principal axis. Its properties depend on the fact that both the incident and the emergent rays are parallel when light is passed through a medium with parallel surfaces.

Images of a double convex lens : In lenses, as in mirrors, the image of an object is the collection of the foci of its several points. Hence the images are real or virtual as the foci, and are determined by the position of a series of points. This may be understood by the illustration of a real image (Fig. 82) :

FIG. 82.



Real and magnified image.

1st. *A large object at a great distance from a convex lens produces a small real inverted image a little beyond the principal focus of the lens, as in an ordinary photographic camera.*

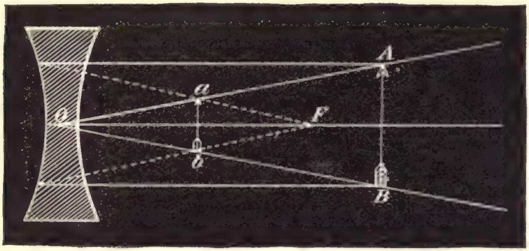
2d. *A small object a very little beyond the principal focus of a convex lens forms a large real inverted image at a considerable distance beyond the principal focus. Illustrated in the case of the projection lantern.*

3d. *In the first case, the greater the distance the smaller the image. In the second, the nearer the object to the focus the larger the image.*

If the object is placed between the lens and its principal focus, a virtual image will be formed, which will be erect and larger than the object. This property is made use of in the magnifying glass. The more convex the lens and the nearer the object to the principal focus the greater the magnifying power.

Images of concave lenses : These images, as the foci, are virtual. They are always erect and smaller than the object. In Fig. 83 the object, *A B*, gives a smaller virtual image, *a b*.

FIG. 83.



Virtual image formed by concave line.

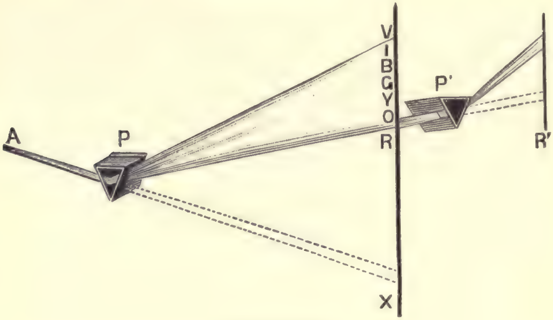
Spherical aberration : In lenses, as in curved mirrors, whose aperture is more than 10° or 12°, the rays passing near the edge are refracted to a point nearer the lens than those passing nearer the principal axis. The images produced are therefore blurred. This is known as *spherical aberration*, and the luminous surfaces formed by the intersection of the rays are called *caustics*. In photography this is overcome by cutting off the rays of light which pass through the edges of the lens. It is also overcome by making the surfaces of the lens parts of unequal spheres, and also by combining a concave and a convex lens.

Decomposition of light : When white light passes from one medium to another, it is not only refracted, but is decomposed into several kinds of light, which are colored. This phenomenon, as we have learned, is known as *dispersion*, and the colored lights form a *spectrum*.

Through a very small opening in the shutter of a dark room admit a beam of sunlight and allow it to pass through a prism and fall upon a screen (Fig. 84). It presents an infinite number of tints which gradually merge into each other. For convenience, seven of these were selected by Newton and spoken of as the *seven primitive colors*—viz., *violet, indigo, blue, green, yellow, orange, red.*

These are the components of white light, and are arranged in the order named, the violet rays being deviated the most.

FIG. 84.

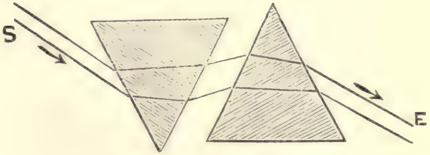


The spectrum.

The colors of the spectrum are *simple,* and cannot be farther decomposed. A pencil of orange rays on passing through a second prism, *P'*, will be refracted, but will remain orange.

Abnormal forms of spectra: The order given is called the normal order, but prisms of different materials disconcert this arrangement. Solutions of indigo and permanganate of potassium each give abnormal spectra. A prism filled with fuchsine deviates the red most and the violet least. The spectra of arti-

FIG. 85.



Recomposition of light.

ficial lights rarely contain all the colors of the solar spectrum; but the order of those they do contain is the same.

Recomposition of white light: By combining the different pencils separated by the prism white light can be reproduced. This can be done in various ways. If a spectrum produced by passing a ray of white light, *S* (Fig. 85), through one prism be immediately passed through a second prism in every way the same as the first, but inverted, the refraction of the two prisms is opposite in direction, the colored rays are reunited, and a white ray, *E*, emerges from the second prism.

By *Newton's disk* it may be shown that the seven colors of a spectrum form white light. This consists of a circular piece of cardboard, the seven sectors of which are colored according to the normal spectrum. When revolved rapidly these colors blend as one, which is nearly white. Were it possible to give each sector its proper intensity of color, the resultant would be white.

The various pencils may also be brought together by a concave mirror, a convex lens, or by a series of plane mirrors so inclined that all their reflected pencils will meet.

Color of bodies: It is the nature of all bodies to absorb or to reflect the light which falls upon them. Those bodies whose surfaces are so constituted that they practically absorb all light, reflecting none, are termed *black;* while those which absorb none, but reflect all, are termed white bodies. Most bodies absorb some light rays and reflect others. They absorb some fraction of primary colors and reflect the remaining portion or complementary color. It is this reflected portion which gives the color.

Mixed colors: The impression of color resulting from the simultaneous action of two or more colors on the eye is single, and we cannot, as in the case of a complex sound, learn to distinguish the constituents, even by practice.

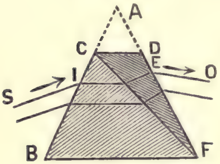
Complementary colors: Any two spectral (not pigment) colors or tints which when mixed produce white light are called complementary colors. One of these tints has a part of the seven primary colors for constituents and the other tint contains the remaining ones. For instance, red and greenish-yellow are complementary; so are orange and Prussian blue.

Color-blindness: This is the inability to recognize one or more of the colors, usually only the red. The eye is abnormal and lacks those sensations which represent this color.

Spectra of different prisms: Prisms of the same angle, made of crown-glass, flint-glass, water, quartz, etc., refract unequally, and when adjusted to refract the red ray through equal angles the violet will be differently deviated. The spectra will have varying lengths. Flint-glass gives about twice as long a spectrum as crown-glass.

Achromatic prisms: An achromatic prism is so constructed that a ray of light passing through it is refracted, but is not decomposed. Different materials having unlike indices of refraction and dispersion are combined as in Fig. 86. *BCF*, a crown-glass section, has its dispersion neutralized by the flint-glass section, *CDF*.

Fig. 86.



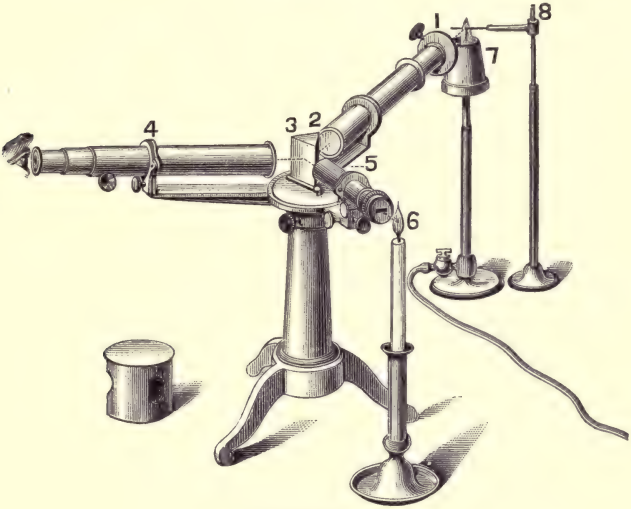
Achromatic prism.

Properties of the spectrum: Besides illuminating properties, the spectrum has heating and chemical properties. The *luminous properties* are most intense in the yellow and least in the violet. The *heating properties* were found by Herschell to be most intense just outside the red, others find the maximum intensity in the red itself. He showed that blackened paper moistened with water dried most rapidly in the red rays and less quickly in succession to the violet. Heat was also found in the dark space beyond the red ray. A galvanometer attached to a thermopile is deflected least in the violet and more toward the red, reaching its maximum just beyond at the point called ultra-red.

The *chemical* properties are greatest in the violet, and decrease abruptly toward the red, but more gradually in the ultra-violet. Organic matter moistened with a solution of silver salts and exposed to light darkens according to the chemical effects of the rays. Experiments based on this fact confirm the statement. It is evident that if light is the result of vibrations of ether, these vibrations are too slow in the ultra-red and too rapid in the ultra-violet to excite vision.

The spectroscope: This is an instrument designed for the study of the spectrum. It is composed of three telescopes mounted on a common stand, whose axes converge toward a prism of flint-glass. Two of the telescopes are fixed, while the third, the one to look through, is movable (Fig. 87). The rays from the flame, 7, pass through telescope 1, being made parallel in it, and fall on the prism, which splits them so as to form a spectrum. This spectrum is then examined by the magnifying telescope, 4, which can be focussed and adjusted. In the remaining telescope is a micrometer scale, the image of which is thrown upon the face of the prism nearest the magnifying telescope, so that both the spectrum and the scale can be seen at the same time. The scale is divided into twenty-five equal parts. The spectrum of any substance can be examined by burning it in the flame, 7.

FIG. 87.



The spectroscope.

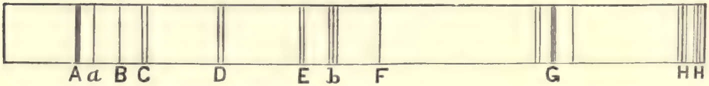
Spectra of various substances: *Solids* and *liquids* heated to a luminous point give *continuous* spectra—that is, a spectrum of unbroken light; gases or vapors give non-continuous spectra, or only *bands* of light, called *banded spectra*.

Every gaseous substance gives its particular lines or bands relative to number, position, and color. These are constant, and when seen in the spectrum always determine the material from which illumination proceeds. The constituents of any gaseous compound give their respective bands of color. Solar light gives bands which correspond in size, number, and position with bands of some of the terrestrial elements. The sun is, therefore, said to contain these terrestrial substances.

Solar spectrum: Sunlight examined through the spectroscope shows a non-continuous spectrum crossed by numerous *dark lines*. Each of these dark lines, so far as studied, occupies the position of the colored bands of various substances. A sodium flame produces a spectrum consisting of a bright yellow line. It might be expected that if this was interposed between an oxyhydrogen lime-light and the spectroscope through which it is viewed, the yellow of the former would intensify that in the continuous spectrum of the latter. Such, however, is not the case; on the contrary, the sodium flame absorbs the yellow of the calcium light, and a dark or black line appears in its place. In the same manner potassium, strontium, and other vapors were found to produce dark lines in a continuous spectrum when intervened between the spectroscope and a calcium light. To this class of phenomena the term *absorbent spectra* is applied, and whenever an incandescent vapor forms a spectrum of bright lines it will produce a reverse spectrum of dark lines when intervened between the spectroscope and an incandescent solid or liquid.

From these facts it is argued that sodium exists in the outer envelope of the sun, and therefore absorbs the yellow ray of light coming from the luminous interior, thus producing a black line. In a similar way is established the existence or non-existence of other elements in the sun.

FIG. 88.



These lines of black are known as Frauenhoffer lines, and were named *A, B, C,* etc., by their discoverer (Fig. 88).

Chromatic aberration: Many lenses, when at a certain distance from the eye, give images with colored edges. This phenomenon, known as *chromatic aberration*, may be explained by the supposition that lenses are composed of a series of prisms, which decompose light as well as refract it. Really there is a different focal length for each color; but we do not notice it in light passing through the centre of the lens. Lenses can be made *achromatic* just as prisms are, by combining two materials of unequal dispersive power. Usually a double convex lens of crown-glass is combined with a diverging concavo-convex lens of flint-glass.

OPTICAL INSTRUMENTS.

Varieties of optical instruments: By the term *optical instrument* we mean a combination of lenses, or of lenses and mirrors. They are divided in three classes according to their purpose:

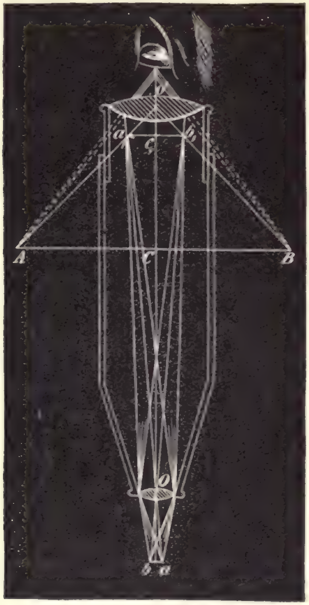
1. *Microscopes*, which give a magnified virtual image of very small objects close at hand;
2. *Telescopes*, by which very distant objects may be observed. Their image is virtual.
3. *Instruments which project upon a screen* magnified or diminished images of objects: of this class are the magic lantern, photographic camera, camera lucida, etc. Except in the case of the camera lucida, the images are real.

The microscope: Microscopes are simple or compound.

The *simple microscope*, or *magnifying glass*, is merely a convex lens of short focal length, which gives an enlarged and erect virtual image of objects placed between it and its principal focus. The nearer the object to the principal focus the larger the image.

The *compound microscope* is designed to produce an image by the aid of a lens and to magnify this image by one or more lenses before it reaches the eye. Suitable adjustments for focussing and illuminating the object are a part of the instrument. The microscope is used to examine objects too small to be seen distinctly by the unaided eye. In its simplest form (Fig. 89) it consists of a short focus lens, *o*, known as the *objective*, for producing the real inverted image $a' \, b'$ of the object $a \, b$; and another lens of longer focus, O', known as the *eye-piece*, which magnifies $a' \, b'$, and gives the virtual image $A \, B$, but does not again invert it.

FIG. 89.



Compound microscope.

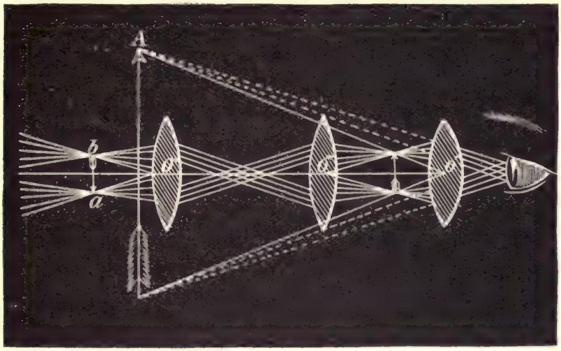
The telescope: There are two forms of telescopes:

1. *The astronomicul telescope*, which, like the microscope, consists of a condensing object-glass, which gives a real inverted and slightly magnified image of the object and a condensing eye-piece which magnifies the image greatly, but does not invert it.

2. *The terrestrial telescope* gives images in their right position. This is accomplished by placing two condensing lenses, O'' and O''' (Fig. 90), between the eye-piece, O', and the objective.

This arrangement furnishes a real and slightly magnified, but not inverted, image of the object for the eye-piece to magnify. In other respects, it is similar to an astronomical telescope.

FIG. 90.

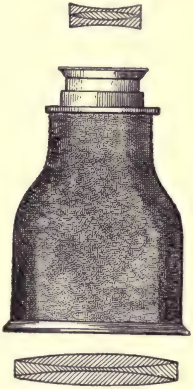


Terrestrial eye-piece.

The *opera-glass* avoids this multiplicity of lenses by using a double concave eye-piece, which magnifies and inverts the inverted image produced by the objective, thus giving the image in its right position (Fig. 91).

The camera obscura: This consists of a closed space or box, impervious to light, having a small aperture by which luminous rays can enter. Rays coming from external objects and entering in this way form on a screen real and inverted images of the objects in their natural colors, but diminished in size. By placing a double convex lens in the aperture and a white screen in the focus of the lens, we can get a brighter and more definite image.

FIG. 91.



The magic lantern: This instrument, which projects magnified images of small objects on a white screen in a dark room, is really a camera obscura reversed. It consists of a light-tight box having, in an aperture on one side, a condensing lens and on the opposite side a concave mirror. A light is placed between the mirror and condensing lens, while in front of the aperture is a movable focussing lens. The rays of light emerge from the condensing lens as parallel rays, pass through the transparency or slide placed in front of the aperture between the lenses, and then pass through the focussing lens, projecting on the screen an inverted real image.

The photographic camera: This is really a camera obscura, and, like it, gives an inverted real image of diminished size. It consists of a light-tight box which has an achromatic lens mounted in an aperture in the front, while at the back there is a ground-glass plate for the reception of the image projected by the lens. The image is focussed on the ground glass by altering the distance between it and the lens. The ground glass is then removed and replaced by a "holder" containing a sensitized plate. The image now falls on this sensitized plate, and causes changes in the nature of its sensitizing agent, imperceptible to the eye, which are revealed by proper treatment with chemicals.

Photography: This, the art of permanently fixing the images produced by the camera, depends on the fact that light alters the chemical nature of certain substances. Silver salts are so affected by light that solutions of chemicals, known as *developers*, reduce them to the metallic state. A plate sensitized with silver salts is exposed in a camera, and the rays which produce the image on it also affect these salts. By the action of a developer the affected salts are deposited as metallic silver on the plate, while the unchanged salts remain soluble in a solution of hyposulphite of sodium. The image produced by the metallic silver is known as a *negative*, because it is the reverse of the conditions which caused it. Wherever the brightest rays from bright parts of objects fall the silver salts are most affected and more silver is deposited; consequently this part of the negative is darker, while those parts are lighter on which fell the less brilliant rays from darker parts of the objects. Other methods depend on the decreased solubility of certain substances after being exposed to light.

The dry plate: The modern dry plate consists of an emulsion of bromide of silver in some vehicle, such as gelatine, spread in a thin layer on glass, celluloid, paper, etc., and dried. It can then be preserved in a light-tight case for a long time, and is always ready for use.

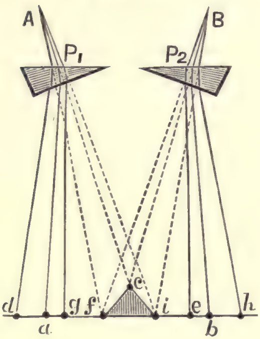
Developing: After a plate has been exposed in the camera it is placed in the developer—for instance, a solution of pyrogallic acid—till enough silver has been deposited to depict the images clearly. It is then placed in a solution of hyposulphite of sodium, which dissolves out all the unchanged silver salts and stops further development. It is kept in the "hypo" solution until it becomes everywhere translucent, and is then washed very thoroughly in water and dried, when it is ready for printing.

Positives or prints: The negative is placed in a holder, a sheet of sensitized paper placed behind it, and the whole is exposed to light. The dark parts of the negative, representing the brightest parts of the original image, intercept the rays of light, so that the parts of the sensitized paper behind them are but little affected, while the contrary holds for portions behind the lighter parts of the negative. Thus the brightest parts of the original image are represented by the lightest parts on the paper, and *vice versa*, the print thus becoming a positive. Further change is prevented by hyposulphite of sodium.

The eye: The eye is really a camera obscura. Rays of light pass through the transparent *cornea*, fall upon the *lens*, pass through it, and throw an inverted real image on the *retina*. The impressions produced by the image on the retina excite in us the sensations of vision. The amount of light which can enter is controlled by the *iris*, which acts as a diaphragm, while alterations in the shape of the lens serve to produce continually a sharply defined image, acting as the focussing power. We do not see objects as inverted, because the brain is only conscious of changes in the retina, and the mind, by sense of touch, learns from the first to associate retinal changes with correct position of the object seen.

Estimation of the size and distance of objects: Our estimation of these depends: 1st, upon comparison with those of known size in the same locality; 2d, upon the visual angle; 3d, upon the optic angle. Regarding the latter, Ganot says: "This angle increasing or diminishing according as objects approach or recede, we move our eyes so as to make their optic axes converge toward the object which we are looking at, and thus obtain an idea of its distance. Nevertheless, it is only by long custom that we can establish a relation between our distance from the objects and the corresponding motion of the eyes. It is a curious fact that persons born blind, but whose sight has been restored by an operation for cataract, imagine at first that all objects are at the same distance."

FIG. 92.



The stereoscope: This is an instrument by which two pictures of the same object taken at a proper angle may appear as one. Each eye sees only the picture opposite it, but by suitable contrivances the two images are made to coincide and appear in the same place.

"Let the left eye be at B (Fig. 92), and the right at A; let a and b be the corresponding pictures for each eye, and P_1 and P_2 two prisms of glass through which they are seen. A prism refracts rays of light, so that objects viewed through it appear to be nearer to the refracting edge; the prism P_1, therefore, refracts the ray aP_1 in the direction P_1A, as if it proceeded from c. The prism P_2 refracts the ray bP_2, so that to the eye at B it also appears to proceed from c. The effect of this is—provided that the two pictures a and b are drawn just as a body at c would appear to the eyes at A and B if the prisms were not there—that the object really appears to be at c. And as the points a and b combine to form the point c, so d and e unite to form the point f, and g and h to form the point i."

Similar effects of relief may be produced by the projection on the same spot of two photographic images of any object taken at a suitable angle to each other.

The ophthalmoscope: This consists of a small concave mirror with a small hole in its centre, through which an observer looks from behind, while he directs a beam of reflected light into the pupil of the patient's eye. In this way the retina can be rendered visible and can be minutely examined. It is fitted with lenses of different powers that may be revolved in front of the observing eye, neutralizing defects in the vision of the patient or observer, and thus rendering the details clearly.

The laryngoscope: This consists of two mirrors. One a small plane mirror attached to a long handle at an angle of about 45°, which is held at the back of the patient's mouth, so that the observer looking into it can see down the throat by reflection. The other is a concave mirror, which reflects light from a lamp to the plane mirror, thus supplying the necessary illumination. It may have an aperture in its centre through which the observer can look.

Sources of light: The various sources of light are the sun and stars; heat; chemical combinations; phosphorescence, and electricity.

1. **The sun and stars** emit a light of unknown origin.

2. **Heat** will produce light, as is shown when solid bodies are heated above 1000° F. They become first red and finally incandescent.

3. **Chemical combination** causes the flame of the ordinary artificial light.

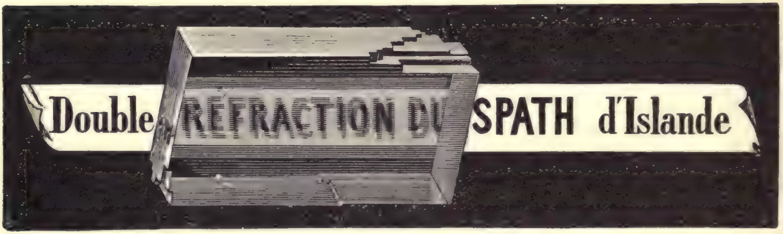
4. **Phosphorescence** is the feeble light emitted by certain substances under certain conditions. It may be spontaneous, as from rotten wood or a glow-worm. Some substances become phosphorescent when heated or acted on mechanically, as by friction. Some forms of electricity produce it, and some substances after being exposed to the sun give off a phosphorescent light for some hours.

5. **Electricity** produces light by heating a poor conductor till it is incandescent.

DOUBLE REFRACTION.

Phenomena of double refraction: Many crystals possess the property of double refraction, by virtue of which an incident ray passing through them is bifurcated. All crystals, except those belonging to the cubical system, possess this power to a greater or less degree; and it can be imparted to those which do not have it originally by compressing them unequally or by heating and then quickly cooling them. Glass in this latter condition is said to be unannealed. Iceland spar (carbonate of calcium) possesses this power to the greatest degree. If a crystal of Iceland spar be placed upon a printed sheet of paper, as in Fig. 93 the letters appear double when viewed through it.

Fig. 93.


Double REFRACTION DU SPATH d'Islande

Double refraction of Iceland spar.

Uniaxial crystals: In all double-refracting crystals there is one optical axis, in some there are two axes, in which this spot is not doubled. These are known as *uniaxial* and *biaxial* crystals, respectively. In all uniaxial crystals this *optic axis* coincides with the axis of crystallization. The *principal plane* of any point on the face of a crystal is a plane through that point at right angles to the face and parallel to the optic axis.

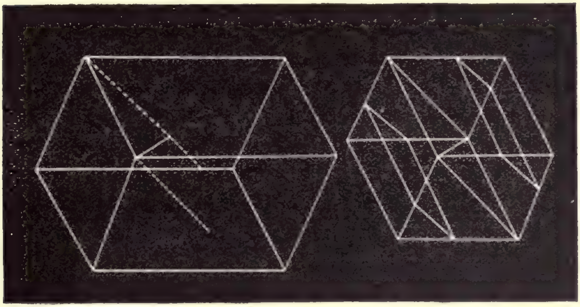
The uniaxial crystals most used in optical instruments are Iceland spar, quartz, and tourmaline.

Ordinary and extraordinary ray: Of the two rays into which an incident ray is divided, that one following the laws of single refraction is called the *ordinary* ray; while the other is the *extraordinary ray*. They produce ordinary and extraordinary images, respectively.

Interference of light: This name is given to the reciprocal action exerted on each other by two rays of light from different sources meeting at an acute angle.

Make two small apertures of the same diameter, and close to each other, in the shutter of a dark room; cover them with a sheet of red glass: two divergent luminous cones will be formed, which meet and overlap each other at a certain distance from the shutter. If a screen is introduced into their path beyond this point, it will be seen that the overlapping segments produce an image composed of alternate red and black bands. On shutting out the light from either aperture the dark bands at once disappear. It is therefore evident that the dark fringes have been caused by the interference of the two pencils when they have crossed; and that, as with sound, two systems of waves may interfere and destroy each other, producing silence, so with light, two systems interfere and produce darkness.

FIG. 94.



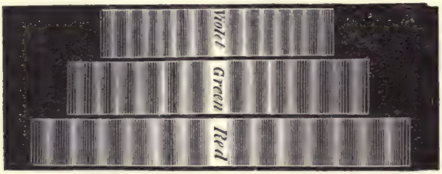
Axis of the crystal.

The same results are obtained with any other homogeneous light, the only difference being in the distances of the bands from each other. This experiment is regarded as giving the most satisfactory evidence of the correctness of the undulatory or wave hypothesis of light. In white light the component colors produce dark bands at different intervals, these being superimposed, but not coincident; the dark lines of one color are illuminated by the others, and a series of colored bands arise.

Diffraction of light: By this is meant the bending undergone by rays of light when passing the edge of an opaque body, in virtue of which some rays penetrate the shadow. If such rays be received on a screen, we can see, within the geometrical limit of the shadow, a faint and gradually diminishing light; while from this same geometrical limit there extends outward a series of alternating light and dark bands or fringes parallel to each other, which gradually disappear.

Gratings: If a pencil of colored light passing though a narrow slit in an opaque screen be received upon white paper, we will see a central band of bright light, and on each side of it a series of similar alternating bright and dark bands. The breadth of these bands and the color of the bright ones depend on the color of the light. If white light be used, a series of equidistant spectra will be formed on each side of the bright line, with their violet side turned inward. By ruling parallel equidistant scratches very close together on glass or arranging a series of fine wires parallel to each other, known as *gratings*, a series of slits will be obtained which will produce *diffraction* or *interference* spectra similar to those produced by a single slit, but of greater brilliancy.

FIG. 95.



Diffraction spectra: These differ in many points from those produced by a prism, and are preferable for scientific work.

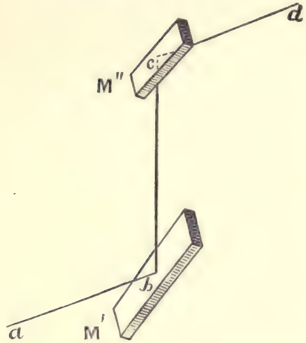
The colors are uniformly distributed in their true order and extent according to wave-lengths, while the spectra give many more dark lines in their exact relative position and extend farther into the ultraviolet.

Newton's rings: All transparent bodies, when in sufficiently thin laminæ, appear colored with very bright tints, especially by reflection ; for example, a soap-bubble or a drop of oil on water. Newton first studied these phenomena as produced by a layer of air interposed between two glasses, one plane and the other convex. With reflected light he obtained a central black spot surrounded by several colored rings. With transmitted light the central spot became white and the color of each ring complementary to that of the ring in the first instance.

Polarization of light: As we have seen, a ray of light passing through Iceland spar is divided into two rays of *equal intensity*—viz., the *ordinary* and the *extraordinary* ray. This effect is called *polarization*, as the extraordinary ray is at right angles to the principal plane, in which the ordinary ray lies. If now the ordinary ray be passed through a second crystal of Iceland spar, it is generally divided into two rays, ordinary and extraordinary, of *unequal intensities*. If the second crystal be turned round until the two principal planes coincide—that is, until the crystals are in similar position—its extraordinary ray disappears, while the ordinary ray is at its greatest intensity. If the second crystal is turned farther round, the extraordinary ray reappears and increases in intensity, while the ordinary ray diminishes, and finally disappears when the two crystals and their principal planes are at right angles. If the extraordinary ray from the first crystal be used, opposite conditions will prevail. When the principal planes coincide, only an extraordinary ray will emerge from the second crystal, and *vice versa*.

Polarization by reflection: When a ray of light falls on a polished, unsilvered glass surface at an angle of 35° 25′ the reflected ray is completely polarized in the plane of reflection. In Fig. 96 let the polarized ray $b\ c$, reflected from M', be received on a second similar surface, M'', at c. If the two surfaces are parallel, the ray is reflected with greatest intensity. If the surface M'' be rotated on $c\,b$ as an axis, the intensity of the reflected ray will diminish gradually, and reflection will cease altogether when the two glasses are at right angles to each other. On turning M'' still farther, the reflected ray will reappear and increase in intensity.

FIG. 96.



Polarization

Angle of polarization: By this term is meant the angle which the incident ray must make with the perpendicular to the polished surface of any given substance in order to produce *complete polarization* in the ray reflected from it. This angle varies for different substances, being 54° 35′ for glass, 52° 45′ for water, and 68° for the diamond.

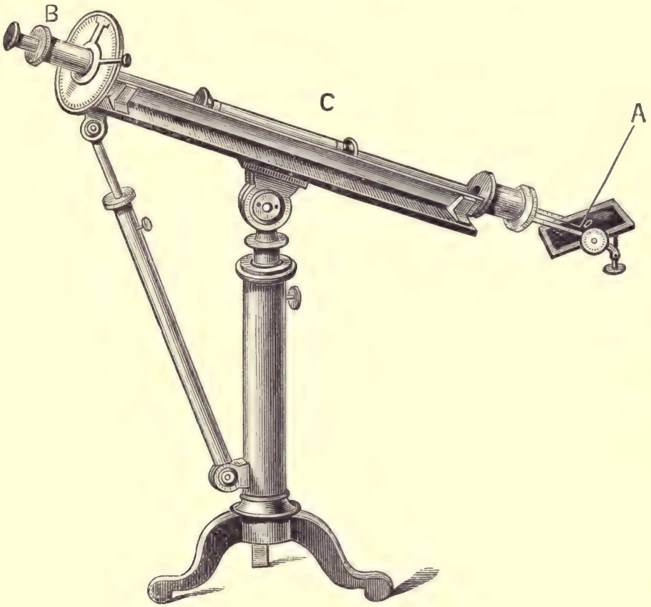
At less angles the ray is only *partially* polarized. In the case of any substance, it is that angle of incidence at which the reflected polarized ray is at right angles to the refracted ray passing through the substance. This refracted ray is also found to be partially polarized.

Theory of polarized light: Polarized light is light which vibrates in only one plane, while ordinary light vibrates in every plane. Polarization splits a ray into two rays which vibrate in planes at right angles to each other. Light may undergo circular, elliptical, and rotary polarization as well as plane polarization, the kind described.

Rotary polarization: Certain substances, especially rock crystal or quartz, possess the power of rotating the planes of polarized light. Take a thin section of quartz cut at right angles to its axis. Let a ray of light be polarized by passing through a crystal of Iceland spar, known as the *polarizer;* and then through a Nicol's prism (which allows only the extraordinary ray to pass), acting as the *analyzer.* Turn the analyzer till the light ceases to pass through it. Then interpose the quartz between the analyzer and polarizer, and it will rotate the ray so that it can pass through the analyzer. Turning the quartz will have no effect. The amount of rotation varies as the thickness of the quartz.

Rotary power of liquids: Many liquids and solutions can rotate light either to the right or left. In this way differences between bodies can be discovered which chemical analysis will not detect. Instruments for applying the principles of polarization are known as *polariscopes*. Biot's polariscope measures the rotary power of liquids, and is especially used for solutions of sugars, wherefore it is frequently called a *saccharimeter*.

Fig. 97.



The saccharimeter: Upon a firm stand is mounted a grooved, movable metallic frame (Fig. 97). At one end of this is the *polarizer*, a mirror, *A*, of black glass. At the other end is the analyzer, *B*, a prism mounted in the interior of a graduated circle, so that changes in its position are read by means of an index traversing the scale. Between these the tube containing the solution is placed, with its axis coincident with the conjoined axes of the analyzer and polarizer. The tube is about 20 centimetres in length. The apparatus is adjusted to have the extraordinary ray disappear when the index is at zero. The introduction of water, alcohol, or ether causes no change in the phenomena observed.

If it is now filled with a solution of cane-sugar, the extraordinary ray reappears; and to cause it to fade the analyzer must be turned to the right of zero through a certain number of degrees, which measures the amount that the sugar has *turned* the plane of polarization to the left. If a longer tube be used with a solution of the same strength, the analyzer must be turned through a greater number of degrees. According as the strength of the solution differs, so does the angle at which the analyzer must be set vary. It is therefore a simple matter to estimate the amount of sugar in any given solution by determining its power to rotate a beam of polarized light.

The principle of polarization is further applied to examine the nature and purity of crystals, for the detection of false gems, and to determine whether the light from heavenly bodies is reflected or is light direct from self-luminous bodies.

MAGNETISM.

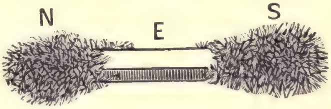
Magnets: Substances which attract iron are called *magnets*, while the term *magnetism* is applied to the cause of this attraction and to the resulting phenomena. Magnets are either natural or artificial.

Natural magnets: Lodestone is the only natural magnet known. It is an oxide of iron (Fe_3O_4), or often a compound of two oxides; and it occurs as an ore, fragments of which, when suspended, tend to point north and south. They were therefore called leading stones or lodestone. The Greeks applied to the ore the name *magnus*, from Magnesia, the city near which it was found. Its property, termed magnetism, is to attract iron.

Artificial magnets: These are made from a few substances which are capable of receiving magnetism. Of the eligible substances, such as cobalt, nickel, and steel, the latter is almost invariably used. When a bar or needle of steel is stroked with a magnet it acquires magnetic properties. Magnets are usually made in the shape of a straight bar, a horseshoe, or a needle. Compound magnets, made of several bars or horseshoes, separately magnetized and riveted together, produce greater magnetic effects than the same amount of iron in one magnet.

Poles and neutral lines: The force of attraction varies in different parts of a magnet. It is strongest at the two ends known as the *poles;* and is totally wanting in the middle, known as the *neutral line.* This may be shown by placing a bar magnet in iron filings (Fig. 98). The ends will be thickly coated with the filings while the middle will be free. The shortest line joining the two poles is known as the *axis.* The end of a freely suspended bar magnet which points north is called the *north pole,* and the other end the *south pole.*

Fig. 98.



Reciprocal action of the two poles: Though the two poles of a magnet act alike when in contact with iron filings, their mode of action is not identical. Suspend a small magnetic needle by a fine thread and bring the north pole of another magnet near its north pole. Repulsion at once takes place between these poles, but strong attraction will be displayed if the north pole of one is brought near the south pole of the other. *Poles of the same name repel, and poles of contrary name attract, one another.*

Theory of magnetism: As a provisional hypothesis to explain the phenomena of magnetism, it has been assumed that there are two *magnetic fluids,* each of which acts repulsively on itself, but attracts the other. The fluid whose action predominates at the north pole of a magnet is called the *north* fluid, and the other the *south* fluid. It is further assumed that these fluids are, before magnetization of any substance, combined round each of its molecules, neutralizing each other;

and that magnetization arranges them in a special order around each molecule, but cannot separate them from it. Probably magnetism results from electrical currents in magnetic bodies.

Inseparability of the poles: If by any means a piece of iron becomes a magnet, one end is always a north and the other a south pole. Broken in pieces, each part becomes a magnet, with its opposite poles; but the reunited fragments retain only their original poles.

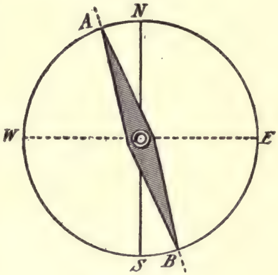
Magnetic substances: Substances which are attracted by a magnet are called *magnetic substances.* They contain the two magnetisms in a state of neutralization, and consequently have no poles. A *magnet* has two poles, and its two magnetic fluids are arranged separately. Most compounds containing iron are magnetic.

Magnetic induction: When a magnetic substance, such as soft iron, is placed in contact with a magnet, the two together form one complete magnet as long as contact remains. The cause of this is known as *magnetic induction* or *influence.* Separate the two, and the magnetic substance can no longer attract, showing that it was only a temporary magnet. Hence we can have *temporary* as well as *permanent* magnets: the former of iron and nickel; the latter of steel and cobalt. Actual contact is not necessary for transforming a magnetic substance into a temporary magnet, provided it be brought sufficiently close to a magnet.

Action of the earth on magnets: The earth is an immense magnet whose poles coincide very closely with the terrestrial poles and whose neutral line is virtually the equator. Its action on magnets follows the law that like poles repel and unlike poles attract. We call that pole of a magnet which is attracted by the north magnetic pole of the earth the north-seeking or north pole, or the marked end of the needle.

Location of the earth's magnetic poles: One is in latitude 70° 5′ north and longitude 96°45′west, a place north and west of Hudson Bay. The other was located in Victoria Land in 1831 by Sir John Ross. These centres are not constant, and therefore cannot be located like a town. They move westward and back eastward within certain limits, requiring a long period of years to complete a single journey. They require about twelve years to move a single degree.

FIG. 99.



Declination.

Declination: By the term *declination* is meant the difference between magnetic and true north, or the angle which the axis of a magnetic needle makes with the geographical meridian of a place when it points toward the magnetic pole of the earth. It is said to be east or west according as it points east or west of this meridian.

At present the declination is to the west in Europe and Africa, but to the east in Asia and North and South America. It shows variations either annual or diurnal, regular or irregular. The latter are called magnetic storms.

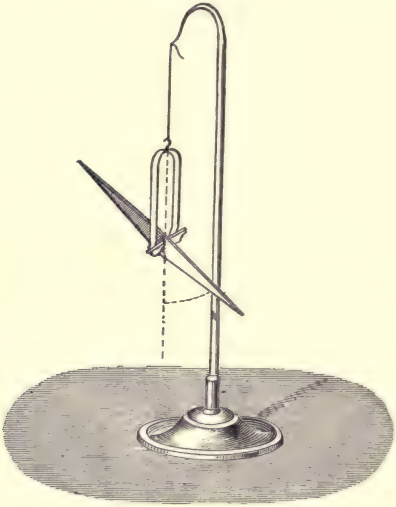
At London, in 1580, the declination was to the east 11°36′; in 1663 it was at zero. Since then it has gradually moved to the west, reaching the maximum of 24°41′ in 1818; thence slowly working its way eastward, and in 1879 was at 18°10′ west.

Magnetic meridian: The magnetic meridian of a place is the vertical plane passing, at this place, through the poles of a movable magnetic needle in equilibrium about its vertical axis. It varies as the magnetic poles.

The compass: The compass is the most important application of the earth's magnetic action. It consists of a cylindrical box, in the centre of which, mounted on a pivot, is a magnetized needle which can move freely. On the bottom of the box are marked the points N., E., S., W. In the mariners' compass a disc of mica is fastened above the magnetic needle, and both are poised on the pivot. On the disc are marked the points of the compass. Of course, as the needle always points toward the magnetic pole and varies as it does, it will only point due north when the magnetic and geographical meridians coincide.

Inclination: Though the magnetic needle points in a northerly direction, the force acting upon it is not situated upon the horizon, but below it. Consequently one pole of the needle will dip downward, except at the equator, where the two forces neutralize each other. North of the equator the north pole dips downward, and south of the equator the south pole. The angle which the needle makes with the horizontal is its *inclination* or dip. At the magnetic poles it is 90° and at the equator 0°.

FIG. 100.



Dip (Deschanel).

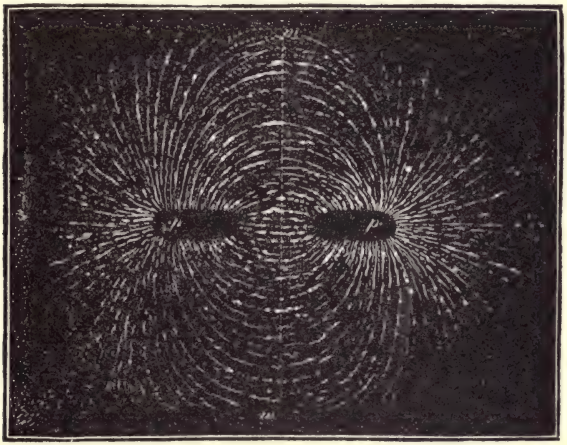
Astatic needle: A combination of two magnets or magnetic needles placed parallel on a common axis and adjusted with their unlike poles adjacent assumes no particular direction relative to the earth's magnetism, but remains in whatever direction it is placed. Remove one of the needles, and the other immediately points toward the magnetic centres. Such a combination of needles neutralizing each other is termed an *astatic needle.*

Law of magnetic attraction and repulsion: Coulomb discovered the remarkable law that magnetic attractions and repulsions are inversely as the squares of the distances.

Magnetic curves: If we scatter some iron filings over a sheet of paper held over the poles of a horseshoe magnet and then tap the paper, we will see that the filings arrange themselves in curved lines stretching from pole to pole, making *magnetic curves* as in Fig. 101.

The direction of the curve at any point represents the direction of the lines of magnetic force at that point. These curves illustrate the law of magnetic attraction and repulsion with regard to distance. A magnetic needle when placed on any curve will take a direction tangent to it.

FIG. 101.



Magnetic curves (Deschanel).

Magnetic field: The space near a magnet undergoes a change in consequence of its presence. This space, known as a magnetic field, is the magnet's sphere of action.

Magnetization: The influence of magnets, either artificial or natural; terrestrial magnetism; and electricity are the sources of magnetism. The principal methods of magnetization by magnets are known as *single touch*, *separate touch*, and *double touch*.

Method of single touch: The pole of a powerful magnet is moved from one end to the other of the bar which is to be magnetized, and this process is repeated several times, always in the same direction. This imparts only a feeble magnetic power.

Method of separate touch: This consists in placing two opposite poles of two magnets of equal force at the middle of the bar to be magnetized and moving them simultaneously toward opposite ends of the bar, then replacing them in their original position and repeating the motion several times. This produces the most regular magnets.

Method of double touch: The two magnets are placed with their poles opposite each other at the middle of the bar, and kept at an equal distance by a block of wood between them. They are then simultaneously moved an equal number of times toward one end and back toward the other, finishing at the middle of the bar. This produces strong but irregular magnets.

Magnetization by action of the earth: As the earth is a magnet, it constantly tends to separate the two magnetisms in soft iron and steel, but it can only produce feeble results. A bar of soft iron held in the magnetic meridian parallel to the inclination becomes at once a feeble magnet. If, when held in this position, it be twisted or struck with a hammer, a feeble permanent magnetism will be acquired which lasts a short time, even after the position is changed. A bar of any iron placed in the earth in a more or less inclined position becomes after a time a feeble magnet, whose north pole is downward. It is this magnetism which, in iron ships, disturbs the action of the compass.

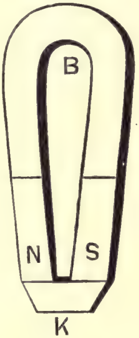
Magnetic saturation: A magnet which has received its full development of force is said to be *saturated*. Among the causes which produce variation in strength is tempering of the steel employed.

The harder the steel the greater its coercive force. It is more difficult to magnetize, but it retains the charge better. The property of a magnet is also dependent upon the percentage of carbon contained in the steel. This also causes a variation in the degree of heat at which it should be tempered. Compass needles are generally tempered at a blue, which is about 300° C.

Increase of heat diminishes intensity of magnetism in a bar; heated to a bright red it completely loses it, and it is not regained with return to its original temperature.

Armatures: Even a steel bar gradually loses its magnetism. To prevent this, *armatures* or *keepers* are used. These are pieces of soft iron placed in contact with the poles, as *K* in Fig. 102. They become powerful temporary magnets, and, by reacting on the magnet, preserve and even increase its permanent magnetism.

Fig. 102.



Powers of magnets: The *portative force* is the greatest weight which a magnet can support. Substances which are attracted are called *paramagnetic*, and those repelled by a magnet are called *diamagnetic* bodies.

Paper, slate, glass, etc., placed between a magnet and a bit of iron do not intercept the attraction; but a partition of iron does impede the magnetic influence. Magnets attract in vacuo as well as in air.

The portative force is increased by hammering or twisting a magnet while it is being magnetized. When a magnet is let fall it loses much of its magnetism.

ELECTRICITY.

Frictional Electricity.

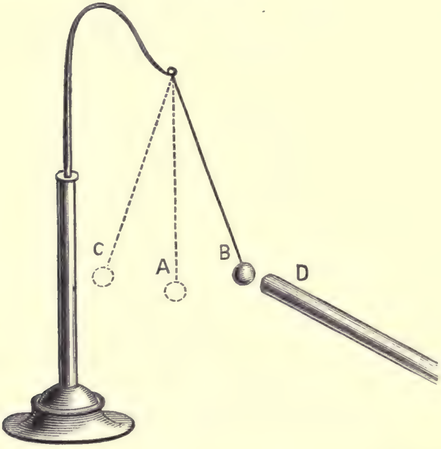
Nature of electricity: Electricity is a powerful physical agent or force, which manifests itself not only by attractions and repulsions; but also by luminous and heating effects; by chemical decompositions, and many other phenomena. The ancients knew that when amber was rubbed with silk it would attract light bodies, and from the Greek name for amber (ἤλεκτρον) the term electricity has been derived.

Many other bodies possess this property. It is, however, not evoked with equal readiness and intensity from all. Amber, sulphur, glass, sealing-wax, caoutchouc, and many other substances, when excited by friction, develop an attraction for light objects, such as cotton and silk fibre, paper and cork, etc. This attraction soon ceases and the electric force soon reverts to an inert state.

Development of electricity by friction: When a glass rod or a stick of sealing-wax is rubbed with a piece of flannel or a catskin, the parts rubbed will become *electrified* and will attract light bodies, which, after remaining in contact for a time, are again repelled.

Electroscopes are used to determine if bodies are electrified. The simplest, the *electric pendulum* (Fig. 103), consists of a pith ball attached by a silk thread to a glass support. When an electrified body is brought near the pith ball the latter is instantly attracted, but after momentary contact is again repelled. These substances which are electrified by friction are called *ideoelectrics;* and those, such as metals, which are not electrified are called *anelectrics.*

Fig. 103.



Conductors and non-conductors: When a dry glass or shellac rod, rubbed at one end, is brought near an electroscope, only the end which has been rubbed will act on it. In such bodies electricity does not pass from one end to the other—they do not *conduct* electricity, and are called *non-conductors.* Metals are good *conductors;* electricity received in any part of a metallic object instantly spreads over its entire surface. Substances are, therefore, divided into conductors and non-conductors; but it is better to regard all bodies as offering *resistance* to the passage of electricity, varying with the substance. As good conductors offer little resistance and non-conductors great resistance, we can say that electrical conductivity is the inverse of electrical resistance. The difference is *quantitative* and not *qualitative,* as there is no absolutely non-conducting substance.

Insulating bodies: Bad conductors are called *insulators,* as, when used as supports for electrified bodies, they prevent the escape of electricity from them. A conductor only remains electrified when it is surrounded by insulators. When an electrified body comes in contact with the earth, a good conductor, all its electricity escapes into it. The earth is therefore called the *common reservoir.* Dry air is a good insulator, but moist air is a conductor; hence the supports of electrical instruments must be dried. If a metal rod is provided with a glass handle, the rod can be electrified by friction, as will be shown by the electroscope. Metals can be electrified, but as they are good conductors the electricity escapes unless they are insulated.

Positive and negative electricity: If a glass rod be electrified and brought near an electrical pendulum, the pith ball will first be attracted, and then, after a momentary contact, in which it too has been electrified, will be repelled. As long as these two bodies remain electrified they will repel each other. An electrified stick of sealing-wax will have the same action on another pith ball; but the two electricities developed are not the same. If the pith ball, which has been electrified by the glass rod, be approached by an electrified stick of sealing-wax, it will be attracted by it; while the pith ball electrified by the sealing-wax will be attracted by the glass rod. The two pith balls will also attract each other, though two balls electrified by the same rod will repel each other.

That force exhibited by the glass has been denominated vitreous or positive electricity, indicated by the sign +, plus; that of the sealing-wax is termed resinous or negative electricity, and bears the sign −, minus.

Theories of electricity: Two theories have been propounded to explain the different effects of electricity. They are:

1. *The one-fluid theory,* which supposes that a peculiar imponderable fluid, which acts by repulsion on its own particles, pervades all matter. This theory further supposes that every body has its normal or natural charge in a state of equilibrium, and that by friction the fluid residing in the body is increased or diminished in quantity, producing respectively positive or negative electricity, by which bodies are positively or negatively electrified.

2. *The two-fluid theory,* which supposes that every body contains an indefinite quantity of an imponderable electric fluid formed by the union of two fluids—the positive and the negative. When combined they neutralize each other. Friction, etc., can separate them; but they are always excited together. A body is positively or negatively electrified accordingly as it retains an excess of one or the other. This theory is quite hypothetical, but is generally adopted for convenience in explaining phenomena.

Development of electricity by friction: When two bodies are rubbed together, the neutral electricity is decomposed. Two electricities are developed at the same time and in equal quantities, one body taking the positive and the other the negative. The electricity developed in a body by friction depends on the substance with which it is rubbed as well as on its own character. Glass becomes negatively electrified when rubbed with catskin; but positively electrified when rubbed with silk. The nature of the electricity set free depends also on other circumstances: When two glass disks of different degrees of polish are rubbed together, the more highly polished one becomes positively electrified; while if two bodies of the same substance, but different temperatures, are rubbed together, the colder one becomes positively electrified. If two similar silk ribbons are rubbed across each other, that which is rubbed longitudinally becomes positively and the other negatively electrified.

Development of electricity in other ways: If a disk of wood covered with oiled silk, and a metal disk, each provided with insulated handles, are pressed firmly together and then separated suddenly, the latter is found to be electrified. A crystal of Iceland spar pressed between the fingers becomes positively electrified; cork, rubber, and a number of substances exhibit the same property if insulated. Sudden separation of bodies develops the best effects.

Cleavage also produces electric disturbance: mica, paper, and all poor conductors, if suddenly separated in the dark, give a flash of phosphorescent electric light. If glass handles are fitted on each side of a piece of mica, and it is suddenly torn asunder, one piece shows positive and the other negative disturbance. A stick of sealing-wax, if broken, shows different electric conditions in its two ends.

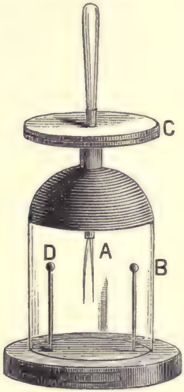
Other sources of electricity, such as chemical action and magnetism, exist. Heat also develops electricity in many substances, tourmaline and cane-sugar being examples.

Identification of the kind of electricity: The *kind* of electricity excited in a body can be identified by presenting it to another having a known electrification, and observing the law that like electricities repel and unlike attack. Glass rubbed with silk becomes positive, with flannel negative.

Gold-leaf electroscope: Gold-leaf is very sensitive and makes a very delicate electroscope. Through the stopper of a glass jar (Fig. 104) passes a metal rod terminating in a knob or disk, *C*. To the lower end are attached two strips of gold-leaf, *A*, face to face. When an electrified body is brought near *C* it decomposes the neutral electricity of the system, attracting to *C* the opposite kind of electricity and repelling the similar kind to the gold leaves, which consequently diverge. This proves the presence of electricity, but not its quality. If we touch *C* for a moment with the finger, all the similar electricity will pass off. Then remove the electrified body, and the system will be charged throughout with electricity of the opposite kind and the leaves will diverge.

Their divergence will be increased if we bring near *C* any body having their kind of electricity, and *vice versa.* This determines the quality.

Fig. 104.



Gold-leaf electroscope.

Electrical unit of quantity: The unit of quantity on the C. G. S. system is that amount of electricity which, acting at a distance of one centimetre across air, on an equal quantity of the same kind of electricity would repel it with a force of one *dyne,* and is called a *coulomb.* A dyne is a force which, acting for one *second* on a *gramme,* can generate a velocity of a *centimetre* per second.

Laws of electrical attractions and repulsions: (1) The electric force decreases as the square of the distance increases.

(2) Like electricities repel; unlike attract.

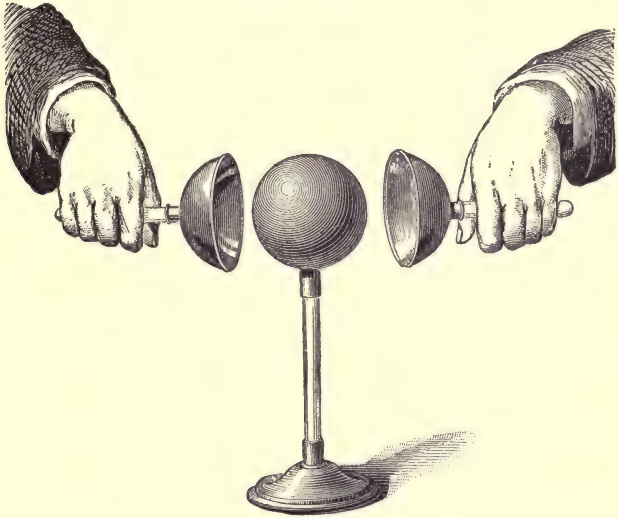
(3) At a given distance the attractive and repulsive forces of electrified bodies are as the product of the quantities of free electricity they contain.

Distribution of electricity: Electricity always resides on the surface in the form of an extremely thin layer. Its distribution depends on the extent and shape of the surface, and not on the mass. If a hollow sphere having an opening on one side be insulated by mounting it on a pedestal of ebonite or glass, and then charged and tested in various parts by the electroscope, the exterior will show the presence of electricity, while the interior is neutral. Provide such a hollow sphere with two hemispherical envelopes which fit it closely and have glass handles (Fig. 105). Electrify the interior of the sphere and cover it with the envelopes. On rapidly removing them they will be found to be electrified, while the sphere is in its natural condition.

The same evidence is shown by substituting for the sphere a conical bag of linen held open at the base by a hoop. The charged bag shows no electricity on the inside, even though it be turned inside out by a silk thread attached to its apex. The electricity is always on the outer side of the bag.

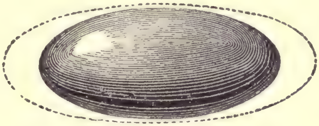
Electric density: By this term is meant the thickness of the layer of electricity on the surface of a body. On a metal sphere the distribution is uniform simply from its symmetry; but on an ellipsoid it is greatest at the ends (Fig. 106); while on a flat disk it collects chiefly at the margin. In other words, as electricity has the greatest tendency to escape at *points*, it assumes greater density or thickness at or near points, edges, or corners.

FIG. 105.



Boit's experiment.

FIG. 106.



Distribution on an ellipsoid.

Electrical tension: By this term is meant the electrical pressure exerted by an electrified body on the non-conducting or *dielectric* medium surrounding it. This pressure is directed outward, and, if continually increased, tends to disruptive discharge.

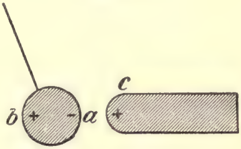
Potential: If two bodies are charged, one with positive, the other with negative electricity, and placed in contact, electricity will flow from the positively to the negatively charged one until neutralization takes place. The former is said to have the higher potential. As water flows only from a higher level to a lower, so also electricity passes only from a higher to a lower potential. The standard used is the earth, which is taken as being zero-potential or the equipotential level. If the potential of a body is higher than that of the earth, it is said to have a *positive potential*, and *vice versa*. A body charged with *free positive electricity* is at a higher potential. Hence electrical potential may be compared to the potential energy of position of a mass resulting from work expended in lifting it against the force of gravitation.

Electrical capacity: The capacity of any conductor is the quantity of electricity it can acquire when charged to the unit potential. Potential is to electricity what temperature is to heat, and might be called electrical temperature. A flash of lightning represents electricity at a high potential, though the quantity is small. The potential increases in the same ratio as the increase of quantity of electricity imparted to a body. Hence the quantity of electricity a body holds is the potential multiplied by the capacity, or $Q = C P$. Compared to a reservoir of water, the pressure is proportional to the depth; but the potential is everywhere the same, for it requires the same amount of work to force water in at the bottom as to raise it to the top and pour it in.

Induction: An insulated conductor, when either positively or negatively electrified, acts on neighboring unelectrified bodies as magnets act on soft iron. It decomposes their neutral fluid into positive and negative constituents, attracting the opposite and repelling the like kinds of electricity. This action is called *induction*. It does not of itself add to or decrease the quantity of electricity these bodies contain. In Fig. 107 the conductor c, charged with + electricity, has decomposed the electricity on $a\ b$, attracting the – part to the end nearest it.

Bodies charged by induction: In the above experiment neither body loses or gains electricity. Bodies, however, can be charged by induction as well as by conduction; but in the latter case the charging body loses part of its electricity, while in the former it does not. The ball $a\,b$ in the above experiment (Fig. 107) can be charged inductively by establishing a connection between the end b and the earth; the + electricity then escapes, but the — electricity is held by force exerted by c. Discontinue the connection with the earth, remove the conductor c, and $a\ b$ will be found to be charged with — electricity.

FIG. 107.

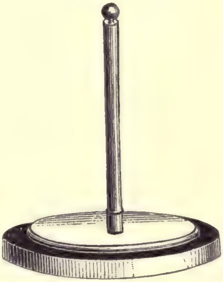


Electrical attraction.

Discharge of electricity: When an electrified insulated body is brought near another body the opposite electricities tend to unite, but are prevented by the resistance of the air. If the density is increased or the distance diminished, this resistance is overcome and the opposite electricities rush together and combine, producing a spark accompanied by a sharp sound. This phenomenon is known as the discharge of electricity.

The electrophorus: This is an instrument by which electricity is obtained continuously and at a minimum of expense. It consists of a metallic ring (Fig. 108) ten inches in diameter. It should be about half an inch high. In the circular space thus formed melted shellac is poured and allowed to harden. A disk of metal, of less diameter than the shellac, is provided; to its centre an insulating handle is attached. Excite the shellac by beating it with a catskin or flannel; then lower the plate or cover upon this, touch the margin of the cover, and a spark escapes; separate it from the shellac, touch its margin, and an-

FIG. 108.



Electrophorus.

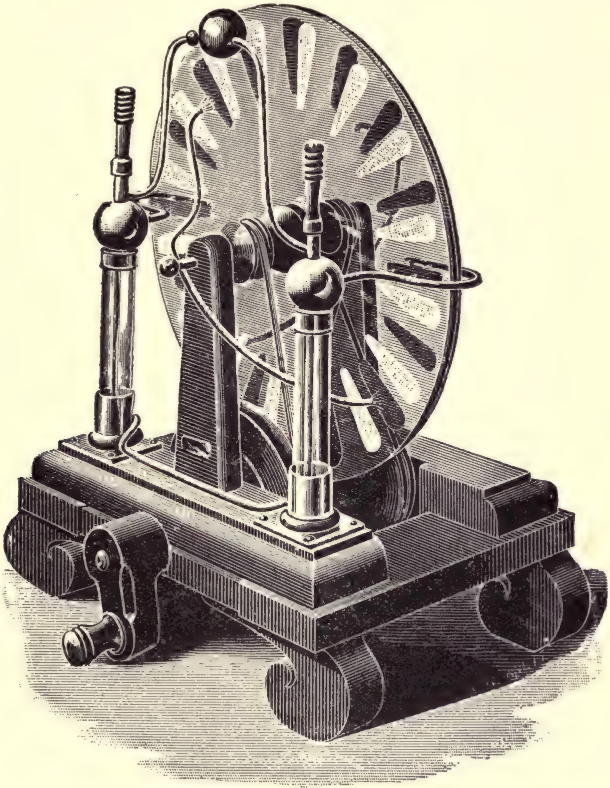
other is obtained. An indefinite number can be drawn from the movable metallic plate by alternately touching it with the finger when laid on the shellac, and when separated from it.

Explanation of action of electrophorus: The cake of shellac is negatively electrified by the beating. It acts on the metallic disk by induction, attracting the + electricity to the lower side, and repelling the — electricity to the upper side. Touching the disk with the finger when in contact with the shellac allows the — electricity to escape, so that *B* is charged positively. Again touching the disk with the finger after separating it from the shellac allows the — electricity on the finger to combine with its charge of + electricity, so that it reverts to the neutral condition. As the shellac is a non-conductor, and also as the contact between it and the disk is not good because its surface is rough, the negative electricity does not escape from it to the disk. If a plate of glass or other material positively electrified by friction were used instead of the shellac, the disk would be charged with negative electricity.

Electrical machines: These are machines for generating frictional electricity in large quantities. The earliest and simplest forms were wheels or cylinders of glass or sulphur revolved against a rubber, thus evoking more or less electricity. These were purely frictional machines, but of late both friction and electrostatic induction are made use of, producing electricity of high potential and giving long sparks. The best of all is the one devised by Wimshurst.

Wimshurst's electrostatic machine: This (Fig. 109) consists of two glass plates so arranged as to revolve with equal speed in opposite directions, each plate having on its outer face the same number—sixteen or more—of equidistant patches of tin foil. The curved metal bar on the front of the machine, set at a slope of 45°, has at its ends brass brushes which make simultaneous contact with a pair of diametrically opposite patches on the front plate. At the back of the machine is a similar bar, at right angles to the one in front, for contact with the back plate. The electricity furnished is collected by horizontal brass combs embracing the sides of the plates and connected with two conductors, one positive and the other negative, which again are connected with two Leyden jars, acting as condensers. The conductors consist of brass spheres, in each of which turns, by means of an insulated handle, a curved arm of brass terminating in a ball. Their distance apart is regulated by rotating the handles.

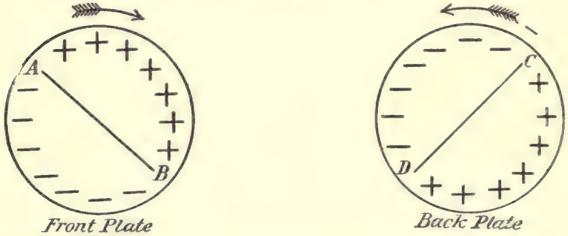
FIG. 109.



Wimshurst's electrical machine (Deschanel).

Production of electricity: The diagram Fig. 110 explains the working of the machine. At the moment when the brushes at *A* and *B* make contact with a pair of tin-foil patches on the front plate, these two patches, together with the rod *A B*, form one conductor, which is influenced inductively by the negative electricity on the back plate opposite *A* and the positive opposite *B*. Thus *A* acquires a positive charge and *B* a negative one. On the back plate, similarly, patches in passing *C* become negatively and in passing *D* positively charged. These charges are carried onward till they are partly delivered up to the combs. Thus the right-hand comb gets positive and the left-hand one negative electricity from both plates. The original electricity is probably derived from the atmosphere, and is increased by rotation of the plates. Very long sparks are obtained from this machine.

FIG. 110.

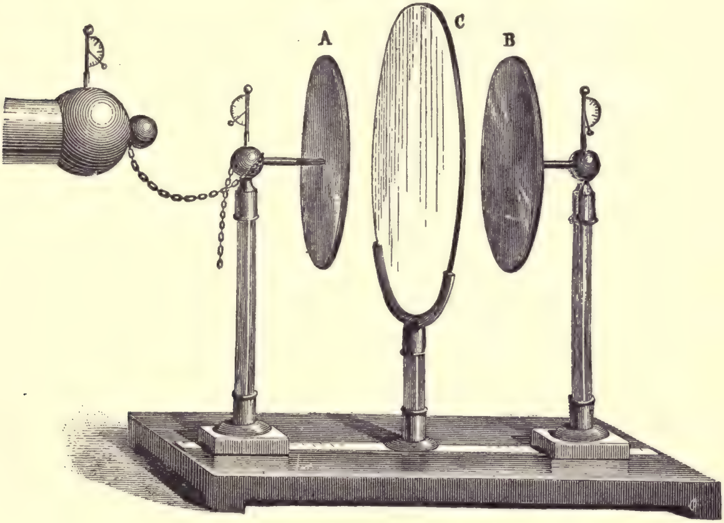


Electric sparks: When the attraction of two opposite electricities is great enough to overcome the resistance of the air, they recombine with a sharp crack and a spark. The spark is instantaneous and its shape varies according to its length. When short it is rectilinear, but when more than two or three inches long it is irregular—a sinuous curve with branches; or if the discharge is very powerful it takes a zig-zag shape.

Condensers or accumulators: These are machines for condensing a large quantity of electricity on a comparatively small surface. They depend on the principle that the capacity of an insulated condenser is increased when it is near another condenser, especially if the latter be connected with the earth; that is to say, it requires a greater quantity of electricity to raise it to a given potential. Their action is well illustrated by Epinus's condenser, though the Leyden jar is the most serviceable form.

Epinus's condenser : This (Fig. 111) consists of two circular brass plates, *A* and *B*, mounted on insulated legs and having between them a glass plate, *C*. *B* is connected with the ground, while *A* is connected with an electrical machine. When *A* is charged with positive electricity it acts inductively on *B*, decomposing its electricity, of which the positive escapes, while the negative gathers on the face nearer the glass; this, in turn, reacts on *A* and attracts its electricity to the surface nearer *B*. This process goes on till the density on *A* has increased to such an extent that the surplus accumulates on the surface away from *B*. When so much electricity has been given to *A* that its density on the part farthest from *A*, which is the part of least density, is equal to that of the charging machine, equilibrium is established and a limit to the charge is reached.

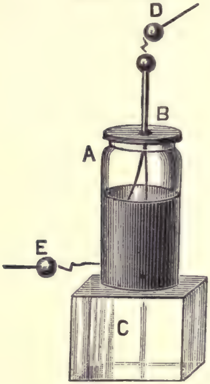
Fig. 111.



Condenser of Epinus.

Leyden jar: This is a modified condenser. It consists of a wide-mouthed glass jar, *A* (Fig. 112), coated externally and internally, nearly to the top, with tin-foil and supplied with a wooden stopper, *B*, through which passes a metal rod attached to a chain, also of metal and sufficiently long to coil upon the lining foil. The outer end terminates in a knob. The two layers of tin-foil act as condensers like the brass plates in the last experiment.

FIG. 112.



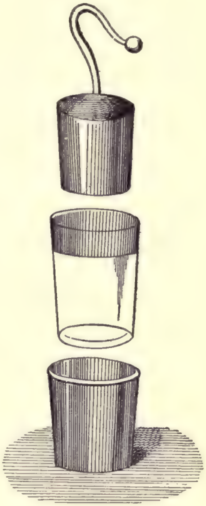
Leyden jar.

Charging a Leyden jar: If the arrangement be put upon an insulated stand, *C* (Fig. 112), and placed near the prime conductor, *D*, of a machine in action, only three or four sparks pass to it. If a knob, *E*, in electric communication with the ground is then brought near the exterior coating, a spark passes to it. For every one passed from the machine to the inner coating another passes from the outer to the knob *E*. This continues for some time, a perfect torrent pouring from the machine to the vial. At last it ceases and the jar is fully charged. Examination shows that if positive electricity is communicated to the inner coating, it is positive electricity which escapes from the outer. But this is not derived from that on the inner coating, as may be seen from the fact that a time arrives at which the action ceases. That the electricity received by the inner coat is still there may be proved by discharging the vial, when an exceedingly powerful spark is obtained and a profound shock experienced, far exceeding in strength that of the sparks communicated to it. A shock will be experienced if *one* hand be placed upon the knob and the other upon the outer coating. The muscular contraction produced by this means is considerable and often dangerous.

Discharge of a Leyden jar: This is effected by means of a curved or jointed metal rod terminating with a knob at either end and supplied with a handle of glass or ebonite. Touching one knob to the outer foil and at the same time bringing the other near to the knob of the jar elicits one or more sparks until the jar is discharged.

Leyden jar with movable coatings: Three tumbler-shaped jars are so fitted that a slight difference in size allows them to be replaced one within another. The middle jar is of glass, the outer and inner jars of tin. When charged the jars can be separated and the two of tin discharged. They give feeble results. The three are again combined and discharged, with an effect showing that the chief charge was not accumulated on the coatings merely, but was stored up in the state of strain into which the glass was put.

FIG. 113.



Jar with movable coatings (Deschanel).

Residual charge: That electricities not only adhere to the surfaces of the insulating medium separating them, but also penetrate it to a certain extent, may be shown in the Leyden jar. Discharge the jar and let it stand a short time. It exhibits a second feeble charge whose strength depends on the length of time the jar has been charged. Then discharge the jar, and after standing a second feebler residue may be found, and so on for a long succession. This is known as the *electric residue.* This residue is nearly proportional to the thickness of the insulator.

Electric battery: This consists of several Leyden jars so arranged that the outer coatings are in communication in one series and the inner in another. Thus constructed, they act as a single jar so intensified as to give severe or even fatal shocks.

Effects of electric discharges: The recombination of the two electricities which constitutes the electric discharge may be either *continuous*, resembling a current, as when two Holtz conductors are joined by a chain ; or *sudden*, as the discharge between two neighboring overcharged conductors. The difference is one of degree and not of kind. The phenomena of the discharges are divided into *physiological*, *luminous*, *magnetical*, *mechanical*, and *chemical* effects.

Physiological effects: These are the effects produced on living beings or those recently alive. In the first case they cause violent excitement of the sensibility and contractility of organic tissues; in the latter they cause violent muscular convulsions.

Among the results of the action of powerful discharges are "burns, superficial and deep, ecchymoses, stripping off the skin of the whole body, deafness, amaurosis, paralysis, lesions of the vascular system, transudations of liquids, and rapid putrefaction." Sometimes the bones are broken, the limbs torn and separated. In one instance the head of a man struck by lightning was crushed as by a powerful blow. On the other hand, strokes of less intensity have cured chronic diseases.

Luminous effects: These are illustrated by the spark which occurs when a Leyden jar is discharged. That there are also *heating* effects is shown when alcohol or coal-gas is ignited by an electric spark.

Magnetic effects: A steel bar may be magnetized by placing it lengthwise inside a spiral of insulated copper wire through which are passed one or more discharges.

Mechanical effects: Objects receiving the discharge are affected according to their conductivity. Bad conductors are penetrated or shattered. A card placed in the path of a spark from a machine or jar will be perforated. The aperture, however, will not be frayed on one side only, as would be the case if a charge had passed from one side to the other. It is frayed on both sides of the card, as if two charges had met within the card and emerged in opposite directions. This fact gives an argument in favor of the two-fluid theory.

Chemical effects: An example of these effects is the formation of *ozone*, a modification of the oxygen of the air, whose odor is perceived when an electric machine is in action.

Duration of the electric spark: The duration is very brief, lasting from 23 to 46 ten-millionths of a second, the time being prolonged by the distance through which the spark travels. This is ascertained by rapidly revolving a card attached to clock-work, each of whose sectors is painted a color in the order and shade or tint of the spectrum. The blending produces a gray color until illuminated by an electric spark. The colors then stand sharply defined as if in a state of rest, showing that the spark has come and gone before the card had time to move sufficiently to produce the blending.

Velocity of electricity: By experiment Wheatstone found that frictional electricity has a velocity of 288,000 miles per second, being greater than that of light. The velocity of dynamical electricity is far less, and, because of induction, the speed of a current in a submarine wire is comparatively slow. The velocity of a constant electric current in a wire which offered no resistance would be about 190,000 miles per second, but in practice it is much less, as wires all offer resistance.

Dynamical, Voltaic, or Current Electricity.

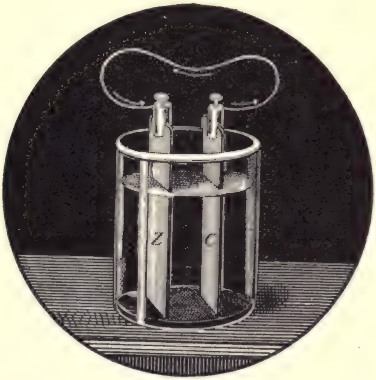
Galvani's experiment and theory: The classical experiment which led to the discovery of dynamical electricity was made by Galvani. He discovered that when the lumbar nerves of a dead frog were connected with the crural muscles by a metallic circuit vigorous contractions resulted. He assumed that these contractions were caused by a form of electricity, the *vital fluid*, inherent in the animal and passing from its nerves to its muscles through the metallic circuit.

Volta's experiment: Volta devoted his investigations to the connecting metals, as it was found that more vigorous contractions resulted in Galvani's experiment when two metals were used in the connecting circuit than when it consisted of only one. He propounded the theory that when two different metals were placed in contact, one assumed the positive and the other the negative condition; also that the phenomena observed in the frog were a result of electricity obtained from the metal or metals, and not from the frog.

Difference between dynamical and frictional electricity: They differ in origin and constancy. Frictional electricity is a condition of tension, and its escape is instantaneous or nearly so. Dynamical electricity is generated by some action tending to produce a current, which flows without cessation until the generators are withdrawn or enfeebled.

Current electricity: When two plates (Fig. 114), one of copper, the other of zinc, are partially immersed in dilute sulphuric acid no change occurs beyond a slight liberation of hydrogen from the zinc plate. If the plates are now placed in contact or connected by a metal wire, a vigorous chemical action sets in and hydrogen is liberated from the copper plate, evidently a new phenomenon not due to mere chemical action. It is found that an electric current passes or flows in the wire from the copper to the zinc, but in the fluid from the zinc to the copper. This action continues while the plates are connected and the material unexhausted. Zinc in a pure state is quickly consumed by the action of the acid ; hence to avoid its dissolution it is usually dipped in mercury previous to using. The current engendered is feeble compared with the discharge of a Holtz machine.

Fig. 114.



Voltaic element.

Voltaic couple: The above arrangement constitutes a *simple Voltaic element* or *couple.* When the metals are connected the couple is *closed;* when not connected it is *open.* In order to establish a current, it is necessary that one of the two metals selected have a greater affinity than the other for the acid. As a matter of economy preference should be given to the durability of the metals. If chemical action create equal potentiality in the two metals, there will be no current. The metal most attacked is called the *positive* and the other the *negative plate.* The *direction of the current* is the direction of the positive electricity through the *wire.*

Electromotive series: According to their electrical action when placed in contact in dilute acid, metals have been arranged in an *electromotive series,* the current in the wire passing from the one lower in the list to the higher. The principal metals in their order are zinc, tin, lead, iron, copper, silver, gold, platinum, and graphite.

Electromotive force: This is the force in virtue of which an electrical current is produced in the wire connecting two metals when they are immersed in a liquid acting unequally on them. It is really a difference of potentials, and is greater as the metals are farther apart in the electromotive series. It is affected by the nature of the liquid and its concentration. The current passes from copper to iron when they are immersed in dilute sulphuric acid, but in the opposite direction when they are placed in solution of potassium sulphide.

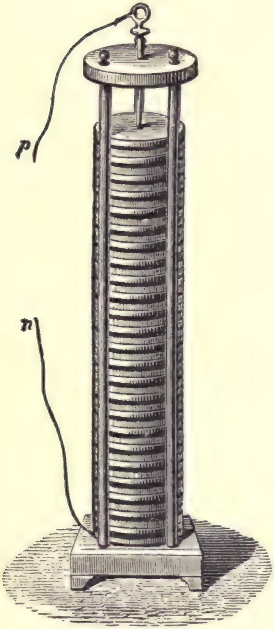
Poles and electrodes: If the wire connecting the two metals of a voltaic couple be cut, positive electricity will tend to accumulate at the end of the wire leading from the negative plate, and negative electricity at the end of the other wire. These terminals are known as the *poles* or *electrodes* of the battery. The *positive pole* is the one connected with the *negative plate,* and *vice versa.*

Voltaic pile: Volta's original apparatus, known as the *voltaic pile,* consisted of a series of discs of copper and zinc, separated by discs of cloth moistened in acidulated water and arranged in sets of zinc, cloth, copper; zinc, cloth, copper, etc. Here the terminal zinc is the negative and the terminal copper the positive pole (Fig. 115).

Voltaic battery: This consists of a series of voltaic couples so arranged that the zinc of one element is connected with the copper of another, and so on. This acts as if it were one large couple.

Polarization: In the earlier forms of electric or voltaic batteries, in which both the copper and the zinc were immersed in the same fluid, it was found that the strength of the current deteriorated rapidly. The result of the action of sulphuric acid on zinc is the production of zinc sulphate and the liberation of hydrogen gas. The latter, collecting in bubbles on the surface of the copper plate, decreased its efficiency by offering resistance and causing counter-currents, a condition known as "polarization" of the plate.

Fig. 115.



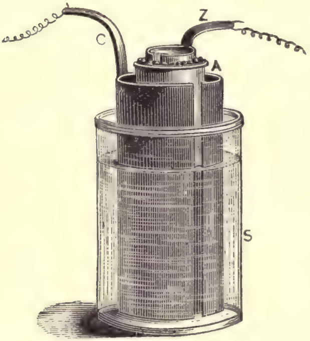
Complete pile.

Constant batteries: Because of the enfeeblement of the current of single-fluid batteries by polarization they have almost entirely gone out of use. They are replaced by two-fluid constant batteries, which give a constant current, preventing polarization by having the negative plate placed in a porous cup filled with some oxidizing substance which will unite with the liberated hydrogen and prevent accumulation. This porous cup is partially immersed in the fluid containing the positive plate.

Daniell's battery: This is the most constant of all batteries. A thin porous cylinder, *A*, filled with dilute sulphuric acid has placed in it the cylinder *Z* of zinc (Fig. 116). This is immersed in a larger glass or porcelain vessel, *S*, filled with a saturated solution of cupric sulphate, in which, encircling *A*, is the cylinder, *C*, of copper. The hydrogen set free by the action of the acid on the zinc passes to the cupric sulphate solution, reducing it to sulphuric acid and depositing metallic copper on the copper plate. Crystals of cupric sulphate placed in the vessel *S* keep up the strength of the solution. The current produced is constant for some hours, and its electromotive force is considered as unity, or 1.

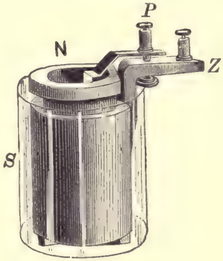
Grove's battery: In this platinum replaces copper as the negative plate and is immersed in nitric acid. These are placed in the inner porous jar *N* (Fig. 117), while the outer jar contains dilute sulphuric acid and the cylinder *Z* of zinc, the positive plate. The hydrogen and nitric acid form hyponitrous acid, which escapes as a gas. The electromotive force is 1.82.

FIG. 116.



Daniell's cell.

FIG. 117.



Grove's cell.

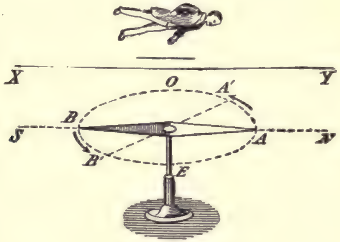
Leclanche battery: In this a rod of carbon, acting as the negative plate, is placed in the inner jar, which is tightly packed with a mixture of oxide of manganese and gas carbon, the whole being covered with a layer of pitch. In the outer jar is a rod of zinc placed in a strong solution of ammonium chloride. The electromotive force is 1.32. This battery is not constant, as the carbon rapidly becomes polarized; but as it quickly regains its strength when left at rest, it is well adapted for such discontinuous work as electric bells.

Local currents: Perfectly pure zinc is not attacked when immersed in dilute sulphuric acid unless it is in contact with copper, platinum, etc. Commercial zinc, however, contains traces of iron or lead, which are electronegative toward it and set up *local electrical currents*, causing the zinc to be rapidly dissolved in the acid. Commercial zinc, when *amalgamated* or coated with mercury, acquires the properties of pure zinc. For this reason the zinc element of a battery is always amalgamated.

Gravity batteries: To obviate the use of two jars, batteries have been devised in which the separation of the liquids is effected by difference of density. A copper plate is placed at the bottom of a jar and has leading from it an insulated wire. A zinc cylinder is suspended at the top of the jar. On the copper plate is placed a layer of crystals of cupric sulphate and the jar is then filled with water. The lower part becomes saturated with the copper sulphate, while the zinc sulphate floats on the surface. The action is that of a Daniell cell, and is both constant and economical.

Measurement of voltaic currents: It has been found that the voltaic current has a peculiar effect on a magnetic needle. In Fig. 118 a copper wire passes horizontally in the magnetic meridian over a magnetic needle. When no current passes through the wire the needle points north; but when a current does pass the needle is deflected, pointing more nearly at right angles to the meridian as the current is stronger. This gives a means of measuring the strength of the current. The north pole is deflected in different directions, according to the direction of the current, and whether it is above or below the needle.

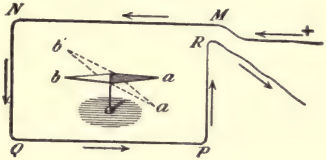
FIG. 118.



Direction of deflection of needle: In the above experiment, where the current passed from south to north over the needle, it deflected it to the west. If we imagine an observer so placed in the connecting wire that he faced the needle and that the current entered by his feet, leaving by his head, the needle would always be deflected toward his left.

Galvanometer: This is a mechanism for determining the strength and direction of a current, depending on the principles just stated. If a magnetic needle is surrounded in the plane of the magnetic meridian by a copper wire forming a complete circuit, as in Fig. 119, it can be seen that a current passing through the wire would have the same action on the north pole at all points of the circuit. If there are many insulated wires in a coil, the action is multiplied. The *galvanometer* or *multiplier* consists of two magnetic needles suspended by a silk thread, the north pole of one over the south pole of the other, and so joined by copper wire that they cannot move separately, the two needles being of slightly different magnetic intensities. The lower needle is suspended inside the coil, while the upper one is above it and records its deflections on a scale, from which the strength of the current can be calculated.

Fig. 119.



Strength of a voltaic current: The current in a voltaic circuit is set in motion by *electromotive force*. The quantity of electricity passing through a section of the circuit in the unit of time is the *intensity* or *strength* of the current. When a current from the same couple is passed respectively through a short and a long wire it is found to have less strength in the latter case, due to greater *resistance* of the longer wire.

Ohm's law: By investigating the action of this resistance Ohm found that the strength of a current was directly proportional to the electromotive force and inversely proportional to the resistance. On this basis he founded the law that *the strength of a current is equal to the electromotive force divided by the resistance,* or, more simply, $C = \frac{E}{R}$.

Resistance of a conductor: This has been found to be inversely as its *conductivity;* constant for each conductor and its *section;* but directly as its *length.* Hence the strength of a current is inversely as the length, and directly as the section and conductivity of the conductor.

Resistance of a cell: There are two kinds of resistance: the *internal,* offered by the liquid conductor between the two plates; and the *external,* offered by the interpolar conductor. Calling the former R and the latter r, Ohm's formula becomes $C = \frac{E}{R + r}$.

Resistance of a battery: If any number, n, of similar elements are coupled together, zinc to copper, the formula becomes $C = \frac{n\,E}{n\,R + r}$. This would give no advantage if r were small, but great advantage if r were very great as compared to $n\,R$.

Arrangement of cells in a battery: From an application of these principles we can find how to arrange the cells of a battery to obtain the greatest effect with the varying values of R and r. Suppose that we have six elements; that the internal resistance R of each element $= 3$; and that external $r = 12$. If the elements were arranged in a single series, zinc to copper, of six elements, $C = \frac{6E}{6R + 12} = \frac{6E}{30}$. If they were arranged, however, so as to form three elements, each of double the surface-area, $C = \frac{3E}{\frac{3R}{2} + r} = \frac{6E}{33}$; which is less in intensity. If, on the other hand, the external resistance was smaller, the intensity in the second case would be greater.

Quantity and intensity of electricity: The normal charge which any body possesses at all times and under all circumstances is its quantity of electricity. This charge may be neutral or excited. In the latter case, either the positive or the negative is in excess. If one species were entirely withdrawn and the other substituted for it, the quantity would remain invariable, but the *kind*, and therefore the *intensity, tension*, or *density*, would be increased. Intensity is the available excess of one of the electric fluids. By increasing the size of the plates used in a battery an increase of quantity is obtained. Tension or intensity, however, depends on the number of cells employed, five hundred producing an electric arc several inches in length, while fifty make a very serviceable battery.

Effects of an electric current: An electric current may produce:

Physiological effects, such as muscular contraction or the stimulation of nerves, observed only when the circuit is closed or opened.

Heating effects, as observed in an electric stove or the safety plug on an incandescent light system, which melts when a sufficiently strong current passes through it. Bodies raised to a very high temperature become incandescent, *luminous effects*, as the spark observed at the point of contact when a circuit is closed or opened. By bringing the two electrodes of a powerful battery close together, a succession of sparks springing across the interval will produce continuous light.

Mechanical effects, including the motion of solids and liquids affected by the current, as the passage of particles of carbon from one pole to the other in the arc of an arc light.

Chemical effects, as shown in the process of electrolysis or of electroplating.

The arc light: If the terminals of the two wires leading from a powerful battery be brought near together, the current will continue to flow across this space and thus produce intense light, which is of short duration, because the heat generated melts the wires and widens the space beyond the traversing power of the current. It is therefore necessary to tip the ends of these wires with some refractory material and to regulate the intervening space by clockwork. Pencils made of carbon answer best for tips, although they waste away and need replenishing. The current always passes from the positive to the negative point, and in so doing carries particles of highly heated, luminous carbon, which either consume themselves or lodge on the negative point. These white-hot particles on their journey furnish light. The negative carbon is built up at the expense of the positive carbon, which is constantly being lessened.

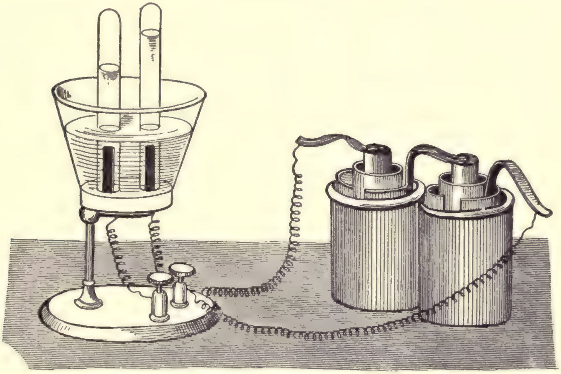
The current, in passing, takes the form of a luminous arc, whence the name. In practice, for reasons of economy, a dynamo is used to furnish the current.

The incandescent light: This depends on the principle that a strong current, when passing through a wire of small conductivity, raises its temperature to the point of incandescence. The lamp consists of a globular glass bulb, hermetically sealed and exhausted of air by a Sprengel pump. Through the base pass two platinum wires fused in the glass. To these is attached a loop of carbon, which becomes incandescent when the current passes through it. The air is exhausted to prevent combustion of the carbon. These lamps give off very little heat, but are not so economical for lighting purposes as the arc lamp.

Electrolysis: By this term is meant the decomposition of various substances by the voltaic current. Many substances, known as *electrolytes*, such as water, etc., can thus be resolved into their elements. The positive electrode is known as the *anode* and the negative as the *kathode*. In Fig. 120 a current is made to pass through water, each electrode being placed under a separate tube. Oxygen is liberated at the anode and hydrogen at the kathode. When salts are decomposed the acid is liberated at the anode and the base at the kathode.

Storage-batteries: It is found that when the platinum electrodes used in decomposing water are disconnected from the battery and connected with a galvanometer they show a current, known as a *polarization current*, opposite in direction to the one which had previously passed through them. Storage-batteries depend on this principle. Red oxide of lead, Pb_3O_4, is spread on two perforated lead sheets, and they are rolled up together with flannel between them and immersed in a jar containing dilute sulphuric acid. A current passed through them changes the red lead on the anode to Pb_2O_4, peroxide of lead; while that on the kathode is changed to metallic lead in a spongy condition. When the primary current is discontinued an opposite current can be obtained till these oxidization-products are reconverted into Pb_3O_4 on both plates. Each sheet is furnished with a binding-screw, by means of which it can be connected with the electrodes of a battery.

FIG. 120.



Voltameter (Deschanel).

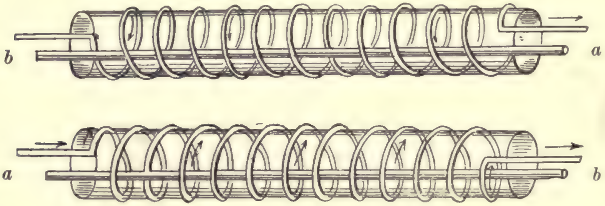
Electroplating: This art, an important application of the decomposition of salts by an electric current, consists in precipitating certain metals from their solutions and depositing them on objects attached to the negative pole, acid being liberated at the positive pole. The essentials for this process are a bath containing a solution of the metal to be deposited and two bars, good conductors, laid across the bath, from one of which is suspended the article to be plated, and from the other a sheet or plate of the metal to be deposited. The negative pole of a constant battery, such as Daniell's, is connected to the rod holding the object to be plated, and the positive pole to the other rod. The metallic plate tends to keep the solution at its normal strength. Special magneto-electric machines are now used to furnish the current. Gold, silver, copper, nickel, and iron are the metals ordinarily deposited.

Electro-dynamics: By this term is meant the action of electric currents upon each other and upon magnets; while *electrostatics* deals with the laws of electricity in a state of rest. It has been found that two parallel currents attract each other if their direction is the same; but repel each other if their directions are contrary.

Action of magnets on currents: Not only do currents acts upon magnets, but magnets also act upon currents. In the galvanometer a current acting on a movable magnet tends to move it to a right angle with its own direction; but if a magnet is fixed while the current passes through a movable wire, the latter is deflected and sets across the direction of the magnet. The earth acts thus as a magnet upon currents passing through movable wire frames, etc.

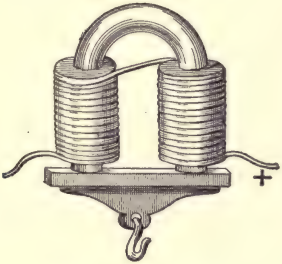
Magnetization by currents: If a bar of steel be placed in a glass tube round which an insulated copper wire is coiled, forming a *solenoid*, and a current be passed through the wire, the bar will speedily become strongly magnetized. The north pole of the bar will be that end to the left of an observer supposed to be swimming in the current and facing the bar. In Fig. 121 the north pole of the soft-iron bar *ab* will be at *a*.

Fig. 121.



Electro-magnets: If a copper wire be insulated and coiled around a piece of soft iron (Fig. 122), and a current passed through it, the iron will become a magnet and remain one as long as the current flows. The iron will, however, cease to be a magnet if the current is interrupted. This magnet is in all its properties similar to an ordinary magnet, but it is not permanent. Such a magnet is called an *electro-magnet*. Of the many forms existent, the usual one consists of two soft-iron cores, joined by an iron yoke, around each of which insulated wire is coiled. These magnets may be magnetized

FIG. 122.



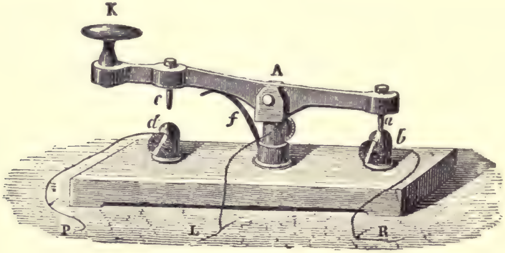
and demagnetized at will by completing and interrupting the current.

Applications of electro-magnets: The applications are numerous. Nearly all electric apparatus owes its effectiveness to the fact that soft iron can be made a temporary magnet to attract the end of an iron lever from a position to which it returns by the aid of *springs* whenever the current is interrupted. Repeatedly making and breaking the circuit moves the lever which sets the simple or intricate clockwork in operation. On the electro-magnet depend electric instruments, such as the telegraph, telephone, electric bells, etc.

Electric telegraph: The essentials of the modern telegraph are (besides wires, batteries, etc.) the *key* and the *sounder*. At first an *indicator* was used to print the messages received, but expert operators soon learned to read these by sound alone, so that the indicator was dispensed with.

Morse's key: This (Fig. 123) consists of a brass lever hinged at the middle, one end of which is kept up by a spring. The line wire is connected with the middle of the lever, while under each end of it is a contact *anvil*. On the end of the lever kept up by the spring is a button for the operator to press, and to the anvil under it is fastened the wire from the line battery. To the other anvil is joined the wire leading to the relay battery and sounder. When the key is up currents arriving by the line wire pass to the sounder. By pressing the key down for a longer or shorter time a corresponding long or short sound, known as *dash* or *dot*, respectively, is produced at other stations on the line.

FIG. 123.



Morse's key.

The sounder: This consists of an electro-magnet whose armature is held apart from it by a spring. When a current passes through this magnet the armature is forcibly attracted toward it, and, striking a brass sounding-piece, produces a *click;* either dot or dash according to its length.

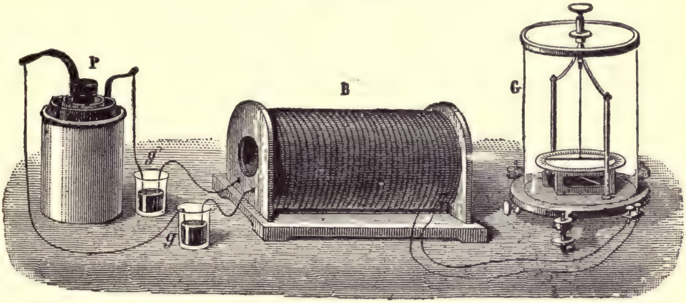
System of telegraphy: At the sending-station the positive pole of the battery is connected with an anvil of the key, while the negative pole is connected with the earth. The line wire leading from the key passes to the receiving-station through its key to the magnet of the sounder and thence to the earth. By using the earth the expense of a return wire is avoided. On circuits over twenty miles in length the current becomes too weak to work the sounder properly, and a *relay* is necessary. This is a second electro-magnet connected with the line wire, which serves, when a current passes through it, to complete the circuit of a local battery connected with the sounder.

Telegraphic code: If the key is depressed so as to be only momentarily in contact with the anvil, the sounder gives only a short click, known as a *dot.* If the contact is longer, the longer click is known as a *dash.* In the code various combinations of dots and dashes represent the letters of the alphabet, as E = dot; A = dot, dash; K = dash, dot, dash; the simpler combinations being used for the letters in more frequent use. The Morse code is in universal use.

Submarine telegraphy: Owing to the length of the wire, another system must be used for this purpose. The wire is connected with a galvanometer on whose needle is a mirror. Reversing the directions of the current causes the needle and mirror to turn to right or left. A light is placed in front of the mirror and the reflections received on a screen. Movement to one side of the middle line constitutes a dash and to the other a dot. In this way messages can be sent.

Voltaic induction: By induction is meant the action which electrified bodies exert at a distance on bodies in the natural state. *Induced currents* are those instantaneous currents developed in metallic conductors under the influence of other metallic conductors traversed by electric *inducing currents* or by the influence of magnets, or even by the earth's magnetic action.

FIG. 124.



Induction by currents: A spool (Fig. 124) is wound with a quantity of silk-covered wire whose ends are connected with a battery, and over this wire is coiled a greater length of similar wire, whose ends pass to a galvanometer. The inner coil is the *primary,* while the outer is the *secondary coil.* While the current is passing through the primary coil no effect is produced on the secondary coil or the galvanometer, but at the moment of breaking the circuit in the primary coil an induced momentary current is produced in the secondary coil ; *direct*, as it has the same direction as the inducing current. On completing or making the circuit another momentary induced current is produced in the secondary coil ; *inverse*, as it has an opposite direction. The galvanometer shows the direction and duration of the induced currents.

Induced currents produced by continuous ones : Induced currents are produced when a primary coil traversed by a constant current is brought near or moved away from a secondary one or when the strength of the current is changed. Wind a great length of fine wire on a hollow spool and connect it with the galvanometer as the secondary coil. Then take a primary coil of shorter and thicker wire on a spool that will fit inside the other one, and connect it with a battery. An inverse induced current in the secondary coil will be produced when the current in the primary coil is made or increased, or when the primary is brought nearer the secondary coil ; while a direct induced current results from the interruption, withdrawal, or diminution of the primary current.

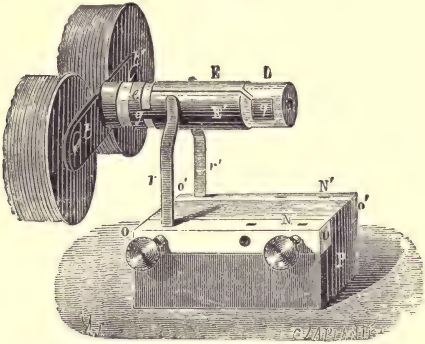
Induction by magnets : This is really only induction by currents. Plunge a bar magnet into a secondary coil and an inverse induced current is produced, lasting as long as the motion of the magnet. Remove it, and a direct current results. The earth exerts magnetic action, inducing currents in coils of wire rotated in the magnetic meridian.

Induction of a current on itself : If a closed circuit of many coils of wire on a spool be suddenly broken, a spark is obtained, due to a *direct extra* induced current produced at the break. When the circuit is again closed a lesser spark is produced, due to a weaker *inverse extra* induced current. These are produced by the action of the wires of the coil on each other at the moment of making or breaking the current.

Magneto-electric machines : The discovery of the fact that induced currents could be produced by the influence of magnets was quickly utilized in the construction of machines for producing electrical currents by the expenditure of mechanical work. The first of these machines, made by Pixii in 1833, consisted of a magnet revolving close to a stationary double coil, in which it generated a current. Clarke soon devised a machine which may be described as illustrating the essential features of this class.

Clarke's machine: In this there is a compound horseshoe magnet fixed in a vertical position. Close to its poles, but in a horizontal plane at right angles to the fixed magnet, is an electro-magnet. This consists of two soft-iron cores wound in opposite directions with a continuous insulated wire and united at the ends by metallic yokes. The electro-magnet is mounted on an axis which passes between the poles of the fixed magnet and through its support. By an appropriate mechanism the electro-magnet can be rapidly rotated, and as it rotates induced currents are produced in the wire, which change their direction at every half turn; being strongest when the plane of the magnet is horizontal, and vanishing when it is vertical. The two free ends of the wire are connected with a *commutator*, by means of which currents in the same direction are produced in the external circuit. The current produced is not constant, but increases and decreases with the position of the electro-magnet.

Fig. 125.

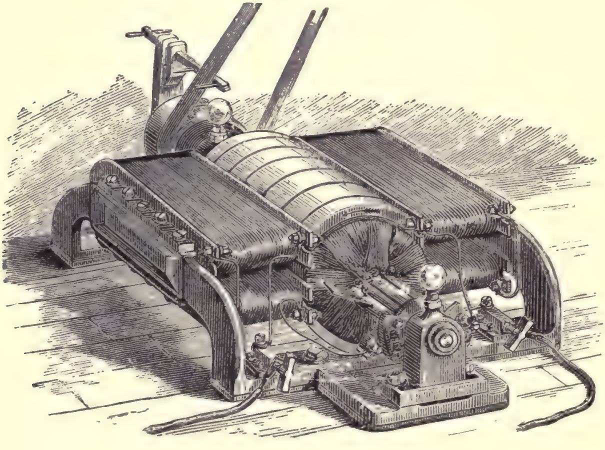


Commutator of Clarke's machine.

Commutator: This consists (Fig. 125) of two brass half-ferrules, E, E', mounted on the axis, but insulated from it and from each other. To these are attached the wires from the electro-magnet. Against these half-ferrules press two contact-springs, r and r'. At the instant of reversal of the current these springs touch only the insulating material between E and E'. When the current is in one direction, say E to E', r is in contact with E and r' with E'. When this current is reversed, r touches E' and r' touches E. Thus, in each case one contact-spring is always positive and the other negative, the current in the external circuit always passing in the same direction.

The dynamo: The important feature of this form of magneto-electric machine is that the magnetism is furnished by the machine itself, the permanent magnet being replaced by an electro-magnet (Fig. 126). Soft iron has usually some traces of permanent magnetism, especially if it has once been magnetized. These traces existing in the fixed or *field* magnet serve to induce a slight current in the revolving magnet—the *armature*—which in turn induces a current in the field

FIG. 126.

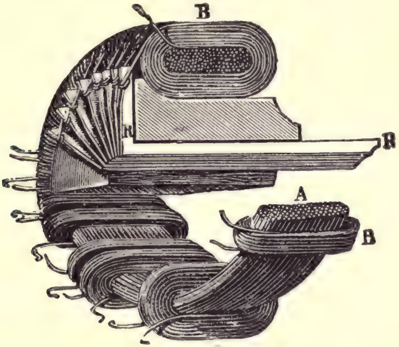


Siemens's dynamo.

magnet, increasing its magnetism and the strength of current it can induce. This process keeps up till currents of great strength are produced.

Armatures: The original armature of Clarke has been greatly improved on. Gramme's armature (Fig. 127) consists of a ring or core made up of a bundle of soft-iron wires. Around this are wound successive coils of insulated copper wire, a free end from each of two adjacent coils being connected with a copper knee-plate, *R R*. These knee-plates, which equal the coils in number, form segments of the commutator and are insulated from each other. The whole is mounted on a wooden block, through which passes the axis of rotation. In passing the two points most remote from the poles the knee-plates rub against two brushes, which therefore form, one the positive, the other the negative electrode. As each brush makes contact with two or more knee-plates, the current is never interrupted and varies but little. In another form of armature the coils are independent, being connected with opposite separate segments of the commutator. Another consists of coils of wire wound lengthwise on a cylinder composed of thin iron discs insulated from each other.

Fig. 127.



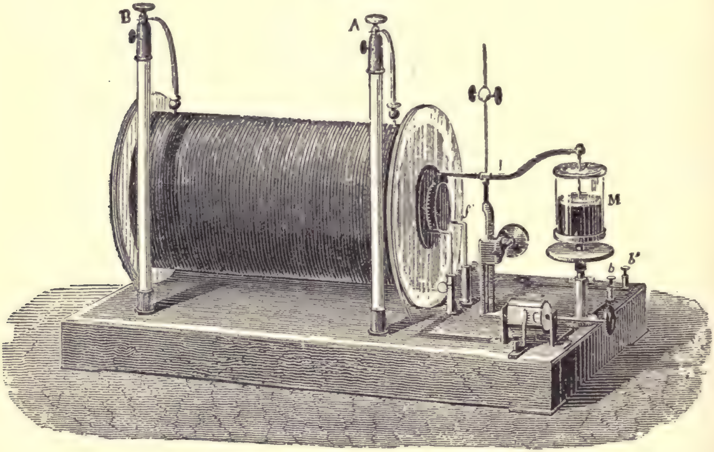
Uses of dymamos: These machines offer a cheap and practical method of producing electricity for many purposes.

Energy in the form of electricity can be transferred from one point to another by means of wires and distributed in any quantity desired. When received it can be transformed into energy by passing the current into an electric motor. There is only about 10 per cent. of loss in this process.

Electric motor: This is simply a dynamo reversed. The current is received in the armature, producing repulsion between the poles of the field magnet and the sections of the armature, and causing it to rotate in a direction opposite to that followed when it produces a current.

Ruhmkorff's coil: This is an apparatus for producing induced currents by alternately making and breaking the inducing current. It consists of an inner primary coil (Fig. 128) of coarse insulated wire wound on a core composed of a bundle of soft straight iron wires. This is covered by an insulating cylinder, around which is wound a great length of carefully insulated fine wire, forming the secondary coil. In large machines the primary coil may be 80 yards and the secondary coil 100 miles in length. The primary coil is con-

Fig. 128.



Ruhmkorff's coil.

nected with a battery by means of an *interrupter* of some kind which rapidly alternates the current. The induced current is of high potential and produces sparks of considerable length. By means of a commutator the current from the battery, may be made to pass in either direction or be cut off entirely.

Crookes's tubes: These tubes were originally devised by Geissler, and bore his name. They consist of closed glass bulbs into which are fused two platinum electrodes. A vacuum is produced in them by the air-pump. Crookes obtained a much more perfect vacuum by using Sprengel's air-pump. An induced current from a Ruhmkorff's coil passing through these electrodes produces a peculiar light.

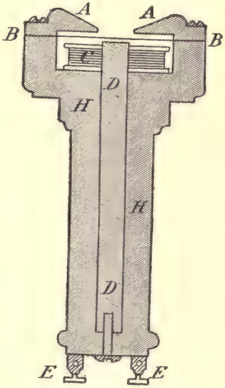
X-rays: This light from a Crookes's tube, termed *radiant* by him, has the property of passing through many substances formerly considered opaque, while glass obstructs it. This light is popularly known as x-rays.

The telephone: The essential features of this machine, as patented by Bell, are represented in Fig. 129.

D, D is a steel magnet about 4 inches long, around one end of which is a spool, *C*, of fine wire, the terminals of which pass to the binding-screws *E, E*. A thin diaphragm, *B, B*, of soft iron is placed close to the end of the magnet and the whole is enclosed in a wooden case, *H, H*.

Two such instruments are used by each operator, one as transmitter and the other as receiver, one binding-screw of each being connected with the line wire and the other with the earth. The diaphragm becomes a temporary magnet by induction. When it vibrates, its centre of magnetism changes, producing fluctuations in the strength of the permanent magnet and consequent alternating currents in the coil. These currents are transmitted over the line wire to the receiver at the other end, where they affect its magnet and cause corresponding weaker vibrations

Fig. 129.



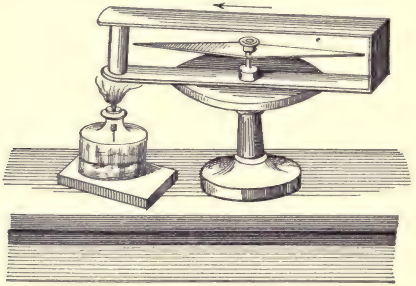
Section of telephone.

of its diaphragm, thereby reproducing the sounds which caused the original vibrations.

Improved telephone: Edison improved the transmitter by fastening a platinum point on the back of the diaphragm and substituting for the magnet a carbon button held in loose contact with the platinum point by a spring. He introduced a battery into the circuit which included the diaphragm, carbon button, and spring, and substituted a return wire for the earth. Vibrations of the diaphragm, by altering the contact between the platinum point and the button, alter the strength of the current and produce corresponding fluctuations in the magnet and resultant vibrations of the diaphragm of the Bell receiver, which is usually used in conjunction with it. The reproduction of sounds by this combination of Edison transmitter and Bell receiver is very perfect.

Thermo-electricity: An electric current, known as *thermo-electric*, can be produced by applying heat or cold to one of the junctions in a circuit composed of two different metals. In Fig. 130 three sides of the rectangular frame are formed of copper, and the fourth of a cylinder of bismuth. It is placed in the magnetic meridian with a magnetized needle in its interior. When one of the junctions is heated the needle is deflected, indicating a current which flows in the copper from the hot to the cold junction, but in the bismuth from the cold to the hot one.

FIG. 130



Thermo-electric current.

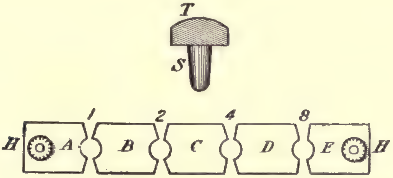
Thermo-electric order: Metals may be arranged, as regards the direction of the current produced by heating the junction of any two of them, in the following order: bismuth, platinum, lead, tin, copper, silver, zinc, iron, and antimony. On heating, the current will pass from one higher in the list to any one which is lower.

Thermo-electric pile: Thermopiles are constructed from which a considerable current can be obtained. A series of seventy or more pairs of bars of two different metals, usually iron and type-metal, or iron and galena, are fastened together at the ends and arranged in the form of a hollow cylinder with the junctions facing alternately inward and outward. The inner junctions are heated by a Bunsen gas-burner, while the outer ones are kept cool by the air.

Electric pyrometer: This apparatus, used for registering very high temperatures, depends on the production of a current by heating the junction of two metals. Two wires, usually platinum and palladium, are joined at one end of each, while the other ends lead to a galvanometer. The end at which they are joined is placed in the furnace or other source of heat, and its temperature calculated from the resultant current.

Rheostat: An instrument which measures the resistance opposed to an electric current is termed a *rheostat*. In principle it is some material of known resistance interposed in the path of a current. By using some adjustable apparatus, as coils of wire, the resistance can be lessened or increased. The longer the coil the greater the resistance; therefore a

FIG. 131.

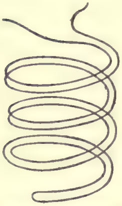


Mode of connecting resistance-coils.

length of wire can be so adjusted as totally to impede the current and thus to indicate the resistance. Resistance-coils and Wheatstone's bridge are the most useful forms of rheostats.

Resistance-coil: This consists of a box, on the top of which are fixed thick brass plates, as in Fig. 131. These can be connected by inserting brass plugs in the holes between them. Coils of German silver wire wound double, as in Fig. 132, unite adjacent ends of the brass plates. These coils are made of such lengths that, by combining several coils, resistance of any integer number of *ohms* up to 5000 or 10,000 can be obtained. When the plugs are inserted there is practically no resistance; but by removing any plug the resistance of its coil is brought in. Hence the resistance between the two binding-screws *H*, *H* will be the sum of the resistances of the unplugged coils.

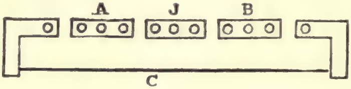
FIG. 132.



Resistance-coil.

Wheatstone's bridge: This consists of a platinum wire of uniform calibre, attached to two stout strips of copper as in Fig. 133. Between these are placed other similar strips at slight intervals, and on all are binding-screws, represented by the small circles, which can be used for attaching the ends of wires or for holding short copper strips to fill the gaps. A sliding contact-key moves along the platinum wire. The wires from a battery are attached to *A* and *B*; the wires from a galvanometer to *J* and the sliding contact-key. In ordinary use the two outer gaps are filled with copper strips, and the two resistances to be compared are inserted in the two inner gaps. When the sliding piece has been so adjusted that the

FIG. 133.



Wheatstone's bridge.

galvanometer is not deflected, showing equilibrium, the two resistances are proportional to the two portions into which the sliding piece divides the platinum wire. Under the platinum wire is a scale equal to it in length and divided in 100 equal parts. If two resistances x and y be compared, of which x is inserted between A and J and y between J and B, and if equilibrium results when the contact-key is at C, 34 points distant from the end nearest A and 66 from the other; then

$$\text{resistance of } x : \text{resistance of } y :: 34 : 66.$$

Electrical conductivity: Conductors may be regarded in two lights; as having more or less *conductivity* or as offering more or less *resistance* to the passage of a current. Conductivity and resistance are the inverse of each other; but conductivity decreases with increase of temperature. Silver and copper offer least resistance for a given volume, while aluminum offers least for a given weight. Liquids are much poorer conductors than metals. If the conductivity of silver be taken as 100,000,000,000, that of distilled water would be 1.

Divided or branch currents: If the electrodes or polar wires be branched or split in several parts, the current will also divide, flowing through each branch in inverse proportion to its resistance. With equal divisions of the wire each section will receive the same fraction of the entire current, and in all cases the currents will be inversely as the cross-sections of the branches. This fact is often used to measure currents which are very strong or to divide a current whose parts are to do work independently.

Electrical units: The practical electro-magnetic units are the *Ohm*, *Volt*, *Ampère*, *Coulomb*, *Farad*, and *Watt*, measured on the C. G. S. system.

Ohm: This, the unit of *resistance*, is the resistance offered by a wire of pure copper 1 millimetre in diameter and 46.25 metres in length.

Volt: This, the unit of *electromotive force*, is best derived from measurements of resistance and strength of current, as it is practically impossible to get a perfectly constant element.

The electromotive force of a Daniell's cell is about a twelfth greater than a volt.

Ampere: This, the unit of *current*, is the electromotive force of one volt in a circuit having a resistance of one ohm. It is sometimes known as a *weber*.

Coulomb: This, the unit of *quantity of electricity*, is that quantity produced by a current of one ampère in one second.

Farad: This, the unit of *capacity*, is that capacity sufficient to hold one coulomb of current having a potential of one volt.

Watt: This, the unit of *energy*, is the energy developed in one second by a current of one ampère having an electromotive force of one volt. It is also known as a *voltampère*. One horse-power is equivalent to 746 watts.

Wireless Telegraphy.

Marconi's system depends on the use of peculiar waves (Hertzian) of the atmospheric ether which are generated by discharges of electricity of high potential. These waves are similar in nature to those producing heat, light, etc. They radiate in all directions but it is not yet known whether they pass through or parallel to the earth's curvature.

At *each station* is a **vertical insulated wire** which extends some distance above the earth's surface.

The **transmitter** is a powerful *Ruhmkorff coil.* Each end of its secondary coil joins a sparking rod, to which is attached a small brass ball. The two balls are set about a quarter of an inch apart, one being also connected with the vertical wire and the other with the earth. A Morse telegraph key is inserted in the circuit between the primary coil and its battery, which consists of a large number of cells. When the primary circuit is closed sparks pass between the balls and, at the same time, successive Hertzian waves are generated from the tip of the vertical wire. The longer the vertical wire the greater the distance at which the waves are perceptible, probably because of increased wave-length. The key enables us to make long or short series of waves thus simulating the dots and dashes of the Morse code.

The **receiver** makes use of the fact that metallic filings in a loose state of contact offer, ordinarily, an appreciable resistance to the passage of an electric current, but when acted on by Hertzian waves this resistance is greatly diminished. Further, the resistance is at once restored to its original value if the filings be shaken up.

Two short silver plugs are tightly fitted into a small glass tube and the interval (about $\frac{1}{30}$ *inch*) between them is partially filled with a mixture of nickel and silver filings.

This tube—the *coherer*—is then exhausted to a vacuum of four millimetres, and the plugs are connected with the poles of a single cell battery, while an ordinary telegraphic relay is inserted in the circuit. One of the plugs is then connected with the earth and the other, either directly or through a small induction coil, with the *vertical wire.* The resistance of the filings ordinarily prevents the action of the relay, but when an impulse from Hertzian waves travels down the vertical wire to the coherer this resistance is so diminished that enough current can pass to work the relay. This closes the circuit of a local battery, which works a Morse printing instrument and also a small hammer, which, tapping the coherer after impulses have been received, restores the original resistance of the filings. A metallic box encloses the receiving apparatus, thus protecting the coherer from the action of the local transmitter.

The *sending key* is so arranged that its back contact will connect the vertical wire with the coherer, thus obviating any change of connections after sending a message. A call is indicated by an electric bell, which is switched during the receipt of a message. It is found that by doubling the height of the vertical wire the distance at which the waves are perceptible is quadrupled.

METEOROLOGY.

Meteorology: The phenomena produced in the air are called *meteors.* They are classed as *aërial,* such as winds, hurricanes, etc.; *aqueous,* as clouds, rain, fog, snow, etc.; and *luminous,* as lightning, the rainbow, or the aurora borealis.

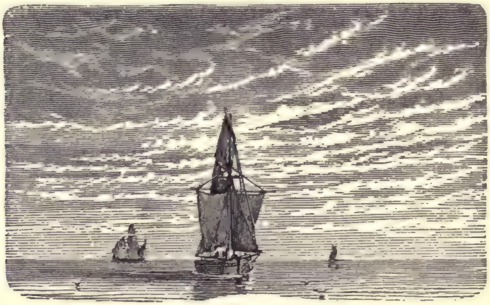
Winds: These are atmospheric currents moving in varying directions with varying velocities, and are named according to their source—*i. e.*, a wind from the north is called a north wind. They are produced by disturbances of atmospheric equilibrium due to differences in temperature between adjacent places. When the atmosphere in any place becomes warmer than that in neighboring places, it rises, while colder air rushes in to take its place. Thus two currents are produced, one flowing outward from the warmer to the colder in the upper strata of the atmosphere, and one flowing in the lower strata from the colder to the warmer place.

Classes of winds: Winds are *regular* when they blow all the year through in a virtually constant direction. These, known as *trade winds*, are due to the greater solar heat at the equator.

Periodical winds are those which blow regularly at the same seasons and at the same hours of the day. The *monsoon*, or the land and sea breezes, are examples of this class, and are caused by more local but regular changes in temperature.

Variable winds blow in one direction or another without being subject to any law.

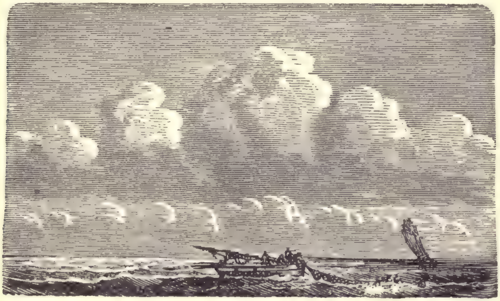
Fig. 134.



Cirrus.

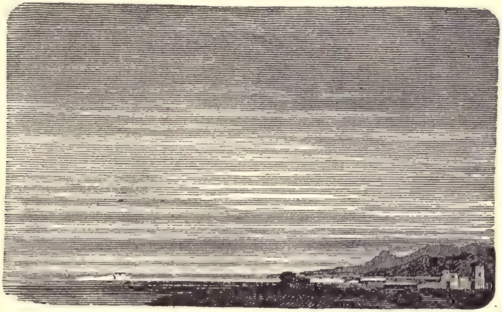
Clouds: When aqueous vapor rises from the earth to colder atmospheric strata it partially condenses into very small globules, forming *fog* or *mist* if near the ground; *clouds*, if far from it. The feathery clouds occupying the highest region of the atmosphere are known as *cirrus* (Fig. 134), or, more popularly, mares'-tails. They are probably composed of particles of ice. When in rounded masses, spherical above and comparatively flat below, the term *cumulus* (Fig. 135) is applied. They are probably the condensed upper extremities of columns of ascending vapor. The horizontal sheets of cloud, probably formed because of the cooling of the earth

Fig. 135.



Cumulus.

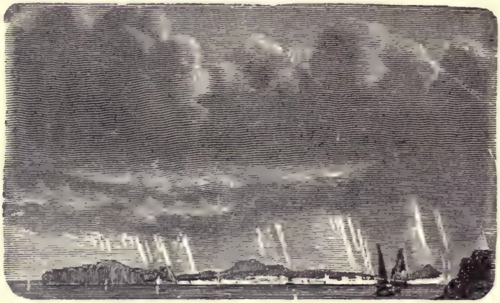
Fig. 136.



Stratus.

and lower air by radiation, are turmed *stratus* (Fig. 136). They form at sunset and disappear at sunrise. Rain clouds, gray in color with fringed edges are known as *nimbus* (Fig. 137).

FIG. 137.



Nimbus.

Rain: It is probable that clouds are always raining, since their component drops tend to obey the laws of gravity. But as there is usually a non-saturated region between the clouds and the earth, the falling drops when very small evaporate before reaching the earth. Ordinary rain-drops are formed by the coalescence of a number of these small particles.

Many local circumstances may affect the quantity of rain which falls in different countries; but, other things being equal, most rain falls in hot climates, as vaporization is there most abundant.

Snow and hail: *Snow* is probably formed by the direct passage of vapor into the solid state. Snow-flakes are always found to be made up of elements possessing hexagonal symmetry.

Hail is probably due to the freezing of rain-drops in their passage through strata of air colder than those in which they were formed. Though, as a general rule, temperature diminishes in ascending, it is no unusual thing for a colder stratum to underlie a warmer.

Dew: As we have seen, dew is the condensation of atmospheric aqueous vapor when in contact with the earth which has been cooled by radiation after sunset. If the temperature of the surface falls below freezing-point, the dew is frozen, producing *hoar-frost.*

Atmospheric electricity: The most frequent luminous phenomena are those produced by free electricity in the atmosphere. Franklin first proved its presence by flying a kite during a thunderstorm and collecting in a Leyden jar the electricity gathered from the clouds. Free electricity is always present in the atmosphere. During fine weather it is always positive; but in stormy weather it is negative as frequently as it is positive. Its origin is not definitely known.

Electricity of clouds: Whatever the origin of atmospheric electricity, there is no doubt that aqueous vapor is the carrier of it. Clouds are in general electrified, but differ in their potentials. Positive clouds are probably formed from vapor which is condensed in higher regions; while negative clouds result from fogs which, by contact with the earth, become negatively charged and then rise.

Lightning: Thunder-clouds may be regarded as charged masses of considerable conducting power. The discharges which produce lightning and thunder occur between two overcharged clouds or between such clouds and the earth. The flashes are often more than a mile long; sometimes four or five miles; and their duration is probably less than the millionth part of a second. *Sheet lightning* is probably produced in the cloud itself, illuminating its mass; while *heat lightning* is ascribed to distant flashes which are below the horizon, but illuminate the higher strata of clouds. They are too far off for an observer to hear the thunder.

Thunder: Lightning and thunder are practically simultaneous, but thunder is heard after the flash is seen, as sound travels much less rapidly than light. Doubt exists as to the cause of the thunder.

Effects of lightning: The effects are those of electricity generally, but, naturally, of great power, killing men and animals, melting metals, igniting combustibles, etc. Persons near whom a flash of lightning passes frequently experience a severe shock by induction, known as a *return shock*, which is less violent than the direct one.

Lightning-rods: As electricity selects the best conductors, it is easy to understand that, if a building be fitted with metallic rods terminating in the earth, lightning will travel through them instead of striking the building. If these rods terminate in points, they enable the earth and clouds to exchange their electricities in a gradual way, thus preventing violent discharges.

Rainbow: This luminous phenomenon appears in the clouds opposite the sun when they are resolved into rain. It consists of seven concentric arcs, presenting successively the colors of the solar spectrum. Sometimes there is only one bow, but usually there are two: a lower one with very bright colors, having red as the highest color; and an external or secondary one, which is paler, and in which the order of colors is reversed, so that the violet is highest. Rarely three bows may be seen, but theoretically more can exist. The phenomenon is produced by the decomposition of the white light of the sun as it passes into the drops, and by its reflection from their inside face. The appearance and extent of the bow depend on the position of the observer and the height of the sun above the horizon; the secondary one ceasing to be visible when the sun is 54° above the horizon.

Aurora borealis: This phenomenon consists of luminous rays, brightest at the bottom, irregular in shape and length, which suddenly alter their intensity, having often red, green, and yellow colors. They are seen at the terrestrial poles, and always converge toward the magnetic pole. Their height is variously estimated at from one to five hundred miles. They are probably caused by electric currents in the higher regions of the atmosphere. Their spectrum coincides with that of nitrogen greatly rarefied and at a low temperature. They are most frequent at the equinoxes, and least so at the solstices.

CLIMATOLOGY.

Mean temperature: The mean daily temperature is that obtained by adding together twenty-four hourly observations and dividing by twenty-four. It coincides very closely with the mean between the highest and lowest temperatures of the day and night.

Alternations in temperature: The principal causes which modify the temperature of a place are its latitude, altitude, winds, and proximity of seas. The farther from the equator the more oblique the sun's rays, and consequently the colder the place. This loss in summer in the temperate and arctic zones is partially compensated by the length of the days. Under the equator, where the length of the days does not vary, the temperature is constant. The altitude of a place has more influence on its temperature than its latitude; the temperature falling, in temperate zones, 1° F. for every 100 yards of ascent.

Winds share the temperature of the countries they have traversed; and therefore their direction has great influence on the air in any place. North of the equator, north winds are proverbially cold and south winds hot; but the reverse holds below the equator.

The neighborhood of the sea tends to raise the temperature of the air and keep it uniform. The average temperature of the sea is always higher than that of the atmosphere.

Gulf-stream: The mildness of the climate of northwestern Europe is mainly due to a current of warm water, known as the gulf-stream. Starting in equatorial regions, it flows through the Gulf of Mexico past the southern shores of North America; then in a northeasterly direction across the Atlantic to Ireland and the northwest of Europe. Its temperature is usually about 10° F. higher than the rest of the ocean on which it floats, and it produces a corresponding effect on the temperature. A cold arctic current, on the other hand, which flows down along the North American coast, is responsible for its colder climate. England and Labrador are in about the same latitude, but differ greatly in temperature.

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